DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH

NEW ZEALAND
JOURNAL OF SCIENCE
AND
TECHNOLOGY

A. AGRICULTURAL RESEARCH SECTION

VOLUME 35.—No. 4 DECEMBER, 1953

Printed for the Department of Scientific and Industrial Research, Wellington,
by
Coulls Somerville Wilkie Ltd., Wellington, N.Z.
DECEMBER, 1953

COMMONWEALTH MYCOLOGICAL INSTITUTE
23 FEB 1954

REGISTERED AT G.P.O., WELLINGTON AS A MAGAZINE

NEW ZEALAND

Journal of Science and Technology

VOLUME 35, No. 4, 1953

(AGRICULTURAL RESEARCH SECTION)

CONTENTS

PAGE

Boron Deficiency and Uptake of Boron in the Hop Plant. *H. O. Askew and R. J. Monk* 279

Effectiveness of Cobalt Sulphate applied to Cobalt Deficient Pumice Land from the Air. *E. D. Andrews* 301

Effect of Soil Acidity on Growth of Pasture Plants. I. *A. J. McNeur.* 311

Effects of Sheep Dung and Urine on a Soil under Pasture. *A. J. Metson and Frances B. Hurst* 327

Elastration and other methods of Castration in relation to Carcass Quality of Fat Lambs. *D. E. Walker.* 360

"Cloud" or Vascular Browning in Tomatoes. III. *E. B. Kidson and D. J. Stanton* 368

Production of Honey Mead from N.Z. Honeys. *T. Palmer-Jones* 375

Seed Disinfection. IX. *I. A. M. Cruickshank and H. Jacks.* 390

Note on the Setting up of a Battery of Small Lysimeters. *C. A. Smith* 394

NOTICES

SUBSCRIPTIONS.—Subscriptions payable in advance. Section A, 18s. per annum; Section B, 18s. per annum; A and B, 36s. per annum. Single copies, 3s.; postage free. Subscriptions should be paid by money-order, postal note, bank note or cheque, and should be forwarded to the Publications Officer, Department of Scientific and Industrial Research, P.O. Box 8018, Wellington. Cheques should be made payable to the Department of Scientific and Industrial Research, and when payable at banks other than in Wellington should have exchange (6d.) added. Subscribers are requested to furnish their full names and addresses.

CORRESPONDENCE.—All communications relative to the Journal should be addressed to the Editor, Department of Scientific and Industrial Research, Wellington.

NEW ZEALAND
JOURNAL OF SCIENCE
AND
TECHNOLOGY

Editor: N. A. Marris, M.Sc., B. Com.
Assistant Editor: M. O'Connor, M.Sc.
Department of Scientific and Industrial Research, Wellington

VOL. 35. SEC. A DECEMBER, 1953 NUMBER 4

BORON DEFICIENCY AND UPTAKE OF BORON IN THE HOP PLANT

By H. O. ASKEW and R. J. MONK, Cawthron Institute, Nelson, N.Z.

(Received for publication, 24 July 1953)

Summary

Failure of normal growth of hops accompanied by distortion of the leaves has been identified as being due to deficiency of available boron in the soil of affected gardens. A low boron content of young shoots is correlated with the presence of the ailment. It is considered that young shoots should contain 20 p.p.m. of boron in their dry matter.

Borax at the rate of ½ oz. per hill has been safe, sufficient and effective in overcoming the deficiency symptoms.

Borax applied as a soil dressing is readily absorbed by the plants, resulting in marked increases in boron content of leaves and cones. Normal boron contents of leaves and cones would appear to be 25 to 50 p.p.m., and 20 to 25 p.p.m., respectively. These values vary from season to season.

The use of magnesite did not affect the intake of boron by the hop plant.

The removal of boron in the hop cones each season corresponds to about 8 oz. of borax per acre.

In plants not treated with borax this represents nearly half of the total intake of boron by the plant.

INTRODUCTION

While the hop plant has attracted a large amount of attention in relation to its nutritional requirements for the major chemical elements, little work has been carried out on its requirements for the minor or trace elements, and in particular for boron. Some information on the effect of hops on the soil has been given by Zattler[1], who reported in 1942 that a grower of sugar-beet had noted in 1937 that the plants on the line of the rows of hop plants, which previously were grown on the area, suffered from heart rot, while those between the old rows of the hops were quite healthy. Zattler suggested that the prolonged use of the ground for hops may have impoverished it in this element. According to Zattler the affected soil of the hop garden in question showed 3 to 5 p.p.m. of boron, while areas growing healthy beet returned 23 p.p.m., thus confirming the theory that the soil was impoverished by the long continued use for hop-growing. This same

worker reported that use of boron on hops gave increased yields. Linke in 1938[2] reported that 2 g. of borax per plant appeared to increase the yield. According to Dennis and Dennis[3], certain soils near Saaz in Germany were considered to be very satisfactory for hops because of their high boron contents. A connection between wild plants growing on certain soils and their suitability for hop growing has been noted. Doerell[4], of Prague, reported a belief current from at least 1769 that land on which wild plums and apples grew was very good for hops: the wild apple has been reported to have a high boron content. Similarly Bertrand[5] said that hops grew well where hemlock is found, and hemlock was rich in boron, showing 18 to 20 p.p.m. in the dry matter. Belgian hop research workers[6] since 1937 have applied small amounts of borax in field trials to examine whether any increase in yield or change in quality occurred, but the largest quantity that was used was equivalent to only 8.8 lb. per acre. No clearly defined effects on either yield or chemical composition were reported beyond a slight increase in the boron content of the cones. No analyses of the leaves were given. In none of the above reports was there any suggestion that growth of the untreated plants was being limited by the level of the supply of boron in the soil. But the fact of carrying out the field trials may suggest that some of the workers may have considered that the supply was sub-optimal. At any rate there was no suggestion that the plants were suffering from boron deficiency.

At Wye College, in England, analyses for boron content showed that marked seasonal variations occurred in the amounts of boron in hop leaves[7]. Position of the leaf on the bine was also a factor controlling the boron content of the leaves. A later report[8] stated that no clear-cut symptoms attributable to boron deficiency had been seen in sand cultures, although there was a tendency for death of the growing point to occur in the absence of boron from the culture solution. In the field, no definite cases of boron deficiency had been noted, although a suspected case on a soil of low boron content was under investigation.

Schropp[9] has published a list of plants for which boron has been shown to be an essential nutrient; this includes the hop. Details of the symptoms have apparently not been published. This is the only report on boron deficiency in hops known to the authors beyond their own made in 1951[10], at which time they were unaware of Schropp's paper. The present authors reported field occurrences of boron deficiency, the main symptoms being death of the growing points of young shoots and distortion of the leaves. Affected shoots were low in boron. Borax at the rate of ½ oz. per hill (37.5 lb. per acre) was effective in controlling the deficiency symptoms. Since that time a great deal more work has been carried out on the boron content of the hop plant and the report on this constitutes the main material of the present paper.

FIELD OCCURRENCE OF BORON DEFICIENCY IN HOPS

In the very dry spring of 1950, growth of hop plants after the initial pruning was very poor in a number of Nelson gardens. New shoots were thick and rigid with poor development of leaves. Internodes were short, with unusually prolific development of laterals, while the leaves were crinkled and distorted, often with suppression of

FIG. 1.—Boron deficient shoots of hops (Californian Variety), showing distorted leaves and development of laterals.

the lobes (Fig. 1). Compared with normal plants, growth was very late in coming away. In many cases, the shoots grew as long as two feet before the tips collapsed and died. In others, the shoots died when much smaller than this, indeed some barely came through the ground before the tips died. This dead tissue was of a warm brown colour (Fig. 2). A very unusual condition was the production of masses of young buds on the crown of the plants just below ground level (Fig. 3). Some of these buds later developed into small shoots. Another very noticeable fact was that replants in general were healthy even in those gardens where established plants were in an unsatisfactory condition. This abnormal growth condition was diagnosed as being due to a deficiency of available boron in the soil, three reasons for this conclusion being:

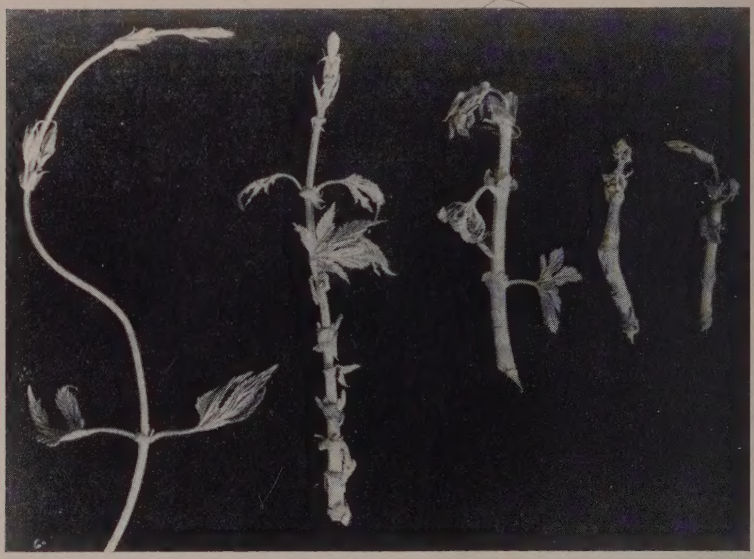


FIG. 2.—Boron deficient shoots of hops (Californian Variety). Healthy shoot on the left.

FIG. 3.—Development of buds on hop crown (Californian Variety).

(1) Chemical data showed that the more severe was the ailment, the lower was the boron content of the corresponding sample material.

A number of samples of young shoots, about 6 in. long, where possible, or of approximately this length where growth was poor, was obtained in November, 1950, from affected and healthy gardens. Comparison material of apparently healthy and definitely affected shoots was also taken in several gardens. While it is not considered good practice to use comparison material of this kind to provide data for distinguishing between the content of a minor element for healthy and unhealthy plant material from an affected area, yet it was thought that by taking the more extreme examples of affected shoots satisfactory differences in boron content might be manifest. In Table I some data are presented for hop shoots sampled as described above. Some information on the soil type and pH values of the soils is included. The occurrence of this unsatisfactory growth condition on the two main series of soils used for horticultural purposes in the Nelson district is in keeping with previous knowledge of the occurrence of boron deficiency ailments in other crops grown on these soil types. In the majority of cases, the pH value of the soil is 6.0 or higher. It is well-known too that boron-deficiency ailments are liable to be more severe the higher the pH value of the soil; but they may occur at low pH values also, especially on sandy soils. The highest figure for boron content of the deficient series, viz. 17.3 p.p.m., was found on a very free sandy area. In all the comparisons given in Table I the affected shoots have in general much lower boron contents than the healthy ones. For the five direct comparisons the average boron contents are: Affected, 9.6 p.p.m.; healthy, 16.6 p.p.m. From somewhat restricted data it would appear that the shoots should show a boron content of not less than 20 p.p.m. in the dry matter.

TABLE I. SHOWING BORON CONTENT OF DEFICIENT AND HEALTHY HOP SHOOTS

Location	Soil type	pH Value of soil	Boron content: p.p.m. on dry matter		
			Deficient	Healthy	Borax-treated
Wai-iti	Motupiko fine sandy loam	6.45	7.5	16.3	50.4
Tadmor	Motupiko fine sandy loam	5.7	9.5	18.4	34.2
Trass Valley	Motupiko silt loam	5.3	13.7	17.5	—
Belgrove	Motupiko sandy loam	6.2	14.0	—	—
Supplejack Valley	Motupiko sandy loam	6.35	—	32.9	—
Neudorf	Motupiko sandy loam	5.75	11.1	14.7	—
Sherry River	Sherry medium sand	6.0	6.0	15.9	—
Umukuri	Sherry medium sand	6.25	17.3	—	—
Umukuri	Sherry fine sand	6.25	—	19.9	—
Riwaka	Riwaka sandy loam	5.35	2.0	—	—

It may be noted that in the garden where only 2 p.p.m. of boron was found in the shoots, only 13 per cent of the plants, many of these being replants, appeared to be healthy, while 37 per cent were apparently dead. Most of the remaining plants were suffering severely from the condition described above. On this area the pH values of the 0–9-in., and 9–18-in. depths of soil were 5.35 and 5.25, and the available boron contents 0.25 and 0.32 p.p.m. respectively.

(2) The pattern of distribution of the ailment and the seasonal conditions were such as had been associated with boron deficiency symptoms in other crops. For example, every plant in an area need not be affected and certain portions might be much more severely affected than others.

(3) Plants treated two seasons previously with borax were quite normal, although neighbouring untreated plants were very poor. The treated hills had been given an application of ½ oz. of borax per hill towards the end of 1948, when boron deficiency in raspberries was being investigated[11]. Nothing untoward was noted in 1948 or later, until the spring of 1950, when it was very obvious, especially in the Wai-iti garden, the first entry in Table I, that the borax applied two years previously was having a markedly beneficial effect. In Fig. 4 is shown a close-up view of an affected plant in this garden from the area outside the block of 13 hills x 5 hills that had been treated with ½ oz. of borax per hill. A typical plant from this top-dressed area is shown in Fig. 5, where the plant photographed has runners 4 ft. or more in length. When the plant of Fig. 4 was

FIG. 4.—Boron deficient hop plant (Californian Variety).

FIG. 5.—Hop plant treated with borax, growing in same garden as the deficient plant of Fig. 4. (Californian Variety).

photographed from the same distance as that of Fig. 5 it was quite inconspicuous and the photograph was thus unsuitable for reproduction.

In the data of the entries for the first two gardens mentioned in Table I, the boron contents of shoots from plants treated with borax were higher than the highest figure of 33 p.p.m. found in a very good healthy garden (Supplejack Valley). It is also evident that the untreated, apparently healthy, material from the first two gardens is somewhat below the 20 p.p.m. of boron which seems to be desirable for satisfactory growth. The appearance of the plants on the treated areas was a strong confirmation of the suspicion that a lack of available boron was the cause determining the development of poor shoot growth in affected gardens.

SURVEY OF BORON STATUS OF HOP GARDENS

A survey of the nutritional status of hop gardens was made by the Soils Laboratory of this Institute in 1949 and a number of the soils of this survey have been used for determination of the available boron content. With the assistance of Mr. E. Chittenden samples of hop

leaves were collected in the first half of February, and cones in early March, 1950, from a number of the gardens covered by the survey of the soils.

In Table II data are given for the soil type, pH value, and (water-soluble) available boron content of the soils, and for the boron contents of leaves and cones of hop plants growing on them. The soils in this table are derived more or less wholly from granite and belong to the Sherry and Riwaka series in the classification made by the Cawthron Institute. The range of pH values is from 5.2 to 6.4 in the former, and from 5.15 to 6.25 in the latter series. Available boron over the whole series varies from 0.25 to 0.64 p.p.m., the Riwaka series being in general somewhat better supplied with boron than the Sherry.

TABLE II. pH VALUE, AVAILABLE BORON CONTENT OF SOIL, AND BORON CONTENT OF LEAVES AND CONES FOR HOPS FROM GARDENS ON SOILS MAINLY OR PARTLY DERIVED FROM GRANITE

Location	Soil type	pH value of soil	Boron p.p.m. on dry basis		
			Soil	Leaves	Cones
Brooklyn	Sherry medium sand	5.9	0.30	14.7	16.4
Umukuri	Sherry sandy loam	6.15	0.42	35.6	16.0
Umukuri	Sherry fine sand	5.7	0.25	25.4	15.7
Umukuri	Sherry sandy loam	6.4	0.63	24.1	15.3
Umukuri	Sherry medium sand	6.4	0.35	25.3	12.1
Riwaka	Riwaka sandy loam	5.2	0.31	28.4	13.1
Riwaka	Riwaka sandy loam	5.45	0.39	21.0	12.1
Riwaka	Riwaka loam	5.15	0.42	26.3	13.2
Riwaka	Riwaka silt loam	5.4	0.49	20.8	—
Riwaka	Riwaka silt loam	6.2	0.40	23.4	15.4
Motueka	Riwaka sandy loam	5.75	0.48	20.7	16.9
Motueka	Riwaka sandy loam	6.0	0.53	35.6	16.7
Motueka	Riwaka sandy loam	6.25	0.44	44.4	19.4
Motueka	Riwaka silt loam	5.8	0.53	39.0	25.8
Riwaka	Riwaka sandy loam	5.5	0.64	44.8	23.8
Riwaka	Riwaka fine sand	5.2	0.37	32.7	13.7

Boron content of the leaves varies, except for 3 samples out of the total of 16, only from 21 to 39 p.p.m. As shown in Fig. 6, where the data for boron content of the leaves have been plotted against available boron content of the soil, it is possible that for a given content of boron in the soil the uptake is not increased at the higher pH levels, the differences in mean values of the two groups of data being only 0.7 ± 3.0 p.p.m. Workers at Wye College[7] found that the boron con-

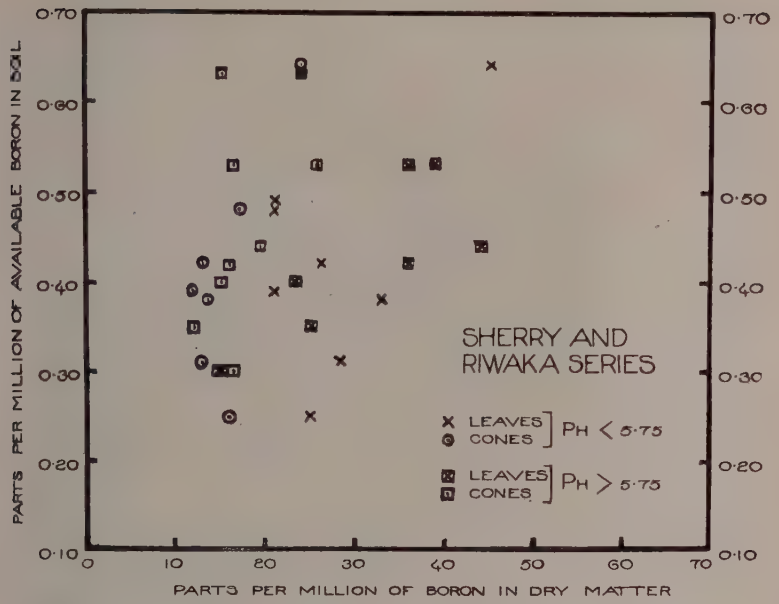


FIG. 6.—Relationship of available boron content of the soil and boron content of leaves and cones on granite-derived soils.

tent of leaves increases with increase in pH value of the soil. In the present series of samples the range in pH values is probably too restricted to make this effect very obvious. With cones, all samples except two contain between 12 and 20 p.p.m. of boron in the dry matter. pH value of the soil (Fig. 6) has exerted no effect on the boron content of the cones, which is, in addition, very unresponsive to variation in the available boron content of the soil.

There are presented in Table III data for 22 gardens on soils of the Motupiko series, which derive mainly from the Moutere Hills formation, and for one garden on Waimea silt loam, which is affected by Moutere Hills material. Most of the soils fall into the sandy loam and silt loam grades. The pH values in Table III range from 5.25 to 6.85, the latter, and similar values, probably being raised from use of generous liming programmes by the growers to whom these gardens belonged. Available boron content of the soil ranges from 0.24 to 0.73 p.p.m., with most of the values lying about 0.4 to 0.5 p.p.m. The data are separated into two series, those where the pH value is less than 5.75, and those where it is greater than 5.75, in Fig. 7. For the cones the boron contents vary between 15 and 25 p.p.m., with no observable effect from either pH value or available boron content of the soil. Leaves vary in boron content from 31 to 46 p.p.m., except for two samples which are appreciably richer in boron; most of the 17 samples contain approximately 40 p.p.m. of boron. The mean values for boron contents of the leaves at pH values less than 5.75 and greater than this figure were 39.2 ± 1.6 p.p.m. and 42.3 ± 2.0 p.p.m. respectively. The difference between them is clearly not significant.

TABLE III. pH VALUE, AVAILABLE BORON CONTENT OF SOIL, AND BORON CONTENTS OF HOP LEAVES AND CONES FROM GARDENS ON SOILS MAINLY OR PARTLY DERIVED FROM MOUTERE HILLS FORMATION

Location	Soil type	pH value of soil	Boron p.p.m. on dry basis		
			Soil	Leaves	Cones
Supplejack Valley	Motupiko sandy loam	6.65	0.25	41.2	23.7
Old House Road	Motupiko silt loam	5.7	0.43	41.0	20.5
Upper Moutere	Motupiko sandy loam	5.95	0.36	41.7	21.9
Upper Moutere	Motupiko sandy loam	5.25	0.41	42.1	15.0
Upper Moutere	Motupiko silt loam	5.4	0.32	—	—
Upper Moutere	Motupiko silt loam	5.25	0.36	—	—
Neudorf	Motupiko sandy loam	6.2	0.73	44.4	22.4
Neudorf	Motupiko sandy loam	5.75	0.24	36.0	18.8
Sunrise Valley	Motupiko sandy loam	5.75	0.38	—	—
Sunrise Valley	Motupiko sandy loam	5.4	0.43	—	—
Sunrise Valley	Motupiko sandy loam	5.65	0.35	—	—
Wai-iti	Motupiko sandy loam	6.4	0.35	31.8	17.3
Wai-iti	Motupiko fine sandy loam	6.45	0.43	39.9	15.9
Hoult's Valley	Motupiko gravelly sandy loam	5.8	0.35	37.0	15.9
Trass Valley	Motupiko silt loam	5.95	0.39	41.0	16.6
88 Valley	Motupiko sandy loam	5.25	0.52	31.7	21.6
88 Valley	Motupiko sandy loam	5.8	0.59	69.9	24.5
Foxhill	Motupiko gravelly sandy loam	6.85	0.66	31.3	18.6
Foxhill	Motupiko sandy loam	6.75	0.58	38.8	16.1
Belgrove	Motupiko sandy loam	5.6	0.52	41.9	20.0
Belgrove	Motupiko sandy loam	6.2	0.48	52.0	19.6
Belgrove	Motupiko fine sandy loam	6.5	0.44	—	—
Waimea West	Waimea silt loam	5.9	0.62	45.5	21.4

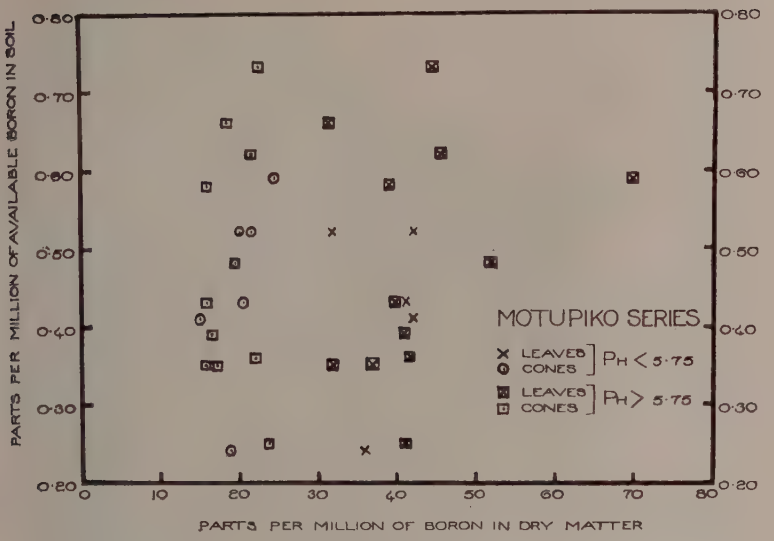


Fig. 7.—Relationship of available boron content of the soil and boron content of leaves and cones for soils of Motupiko series.

A further breakdown of the data for the Moutere-derived and granite-derived soils into three groups of average pH values of 5.3, 5.8 and 6.2–6.5 did not suggest any closer correlations between pH value and boron content of leaves and cones.

The data presented show that appreciable variations in boron content of soils, and of leaves and cones of hop plants occurred throughout the Nelson district. The values for the cones may be compared with the figure of 24.4 p.p.m. reported for Hallertau variety of hop grown in Belgium[6]. Some of the gardens for which low values had been found were later used in field experiments to see whether applications of boron would be of benefit to them.

Field Trials

Data for samples obtained in February, 1950, indicated that there were some differences in the boron content of leaves from the bottom, middle and top thirds of a plant. These were usually not very great, e.g., in one case varying from 29.8 p.p.m. for the bottom third to 24.2 p.p.m. for the top third; leaves from laterals were lower still, being 21.2 p.p.m. in this series. It was decided to make it standard practice to take for samples leaves from the top third of the main bine close to the clusters of cones. Samples of cones were taken from the top of the plants. It may be noted that for English hop plants boron contents of the leaves varied with height on the bine[7].

Since ½ oz. of borax was apparently sufficient and safe to apply per hill, provided it was spread in a ring of about 18–24 in. diameter and not directly over the hill, it was decided to take this amount as a basis

for experimental quantities to apply. Most of the Nelson hop gardens are planted 6 ft. by 6 ft. so that an application of ½ oz. per hill corresponds to an acre rate of 37½ lb.

In 8 out of the 10 gardens reported upon in Table IV, the plots consisted of two rows of five plants each, the plots being surrounded at sides and ends by guard rows. In the other two gardens smaller plots were used. Three replications of the following treatments were provided, except that at garden FA only two replications could be obtained: (1) Control, no boron or magnesium; (2) Borax, ½ oz. per hill; (3) ground magnesite, containing about 20 per cent of acid-soluble magnesium (MgO), at the rate of 1 lb. per hill, distributed over a circle of about 3 ft. diameter; and (4) Borax and magnesite at the above rates. Magnesite was included because of the occurrence of magnesium deficiency in various crops of the district. Only the effect, if any, of the magnesite on the boron content of the leaves and cones of the hops will be considered here. The treatments were applied at the end of September and early in October, 1950. In all the gardens the Californian variety of hops was grown.

TABLE IV. pH VALUES AND AVAILABLE BORON CONTENTS OF SOILS FROM HOP GARDENS WHERE FIELD TRIALS WITH BORAX AND MAGNESITE WERE ESTABLISHED

Garden	Soil type	pH Value		Available Boron p.p.m.	
		0–9 in.	9–18 in.	0–9 in.	9–18 in.
C	Sherry medium sand	6.25	6.5	0.22	0.17
FA	Sherry medium sand	6.0	5.9	0.35	0.37
D	Sherry fine sand	6.25	5.9	0.31	0.29
FY	Sherry medium sand	6.35	6.0	0.19	0.24
R	Riwaka sandy loam	5.9	6.05	0.42	0.22
FR	Riwaka silt loam	6.55	6.15	0.12	0.26
H	Motupiko sandy loam	6.35	5.85	0.30	0.20
P	Motupiko sandy loam	5.75	5.3	0.28	0.27
L	Motupiko fine sandy loam	6.45	6.5	0.30	0.27
G	Motupiko silt loam	5.3	5.2	0.29	0.32

Data for the pH values and available boron contents of the soils of the experimental areas, sampled on 5 Feb., 1951, towards the end of the 1950-51 growing season, are given in Table IV. Except for two soils of low pH value and two of higher value, most of the soils have pH values close to 6.0 in the 0–9-in. depth. Variation in pH value between the top and lower sections for a given soil is not great. Available boron content ranges from 0.12 to 0.42 p.p.m. in the topsoil, and from 0.17 to 0.32 p.p.m. in the lower portions. The boron content of the subsoil thus may be lower or higher than that of the topsoil. In this series, the two gardens that showed the greatest incidence of boron

TABLE V. BORON CONTENT (B), IN PARTS PER MILLION ON THE DRY BASIS, FOR HOP LEAVES AND CONES FROM HILLS TREATED WITH BORAX AND MAGNESITE FROM GARDENS ON SOILS DERIVED LARGELY, OR PARTLY, FROM GRANITE

Garden	Treatment	Leaves				Cones			
		1950 (p.p.m.)	1951 (p.p.m.)	1952 (p.p.m.)	1953 (p.p.m.)	1950 (p.p.m.)	1951 (p.p.m.)	1952 (p.p.m.)	1953 (p.p.m.)
C	Control	14.7	37.9	25.2	37.1	16.4	29.3	16.5	25.7
	Borax	—	325.2	56.2	255.2*	—	48.3	23.7	44.9*
	Magnesite	—	66.3	27.0	61.9	—	26.4	18.7	26.4
	Mg + B	—	298.9	58.5	256.3*	—	47.4	23.6	38.9*
FA	Control	—	48.6	52.0	47.1	—	25.4	22.8	18.4
	Borax	—	207.6	102.2	305.7*	—	44.1	29.1	39.3*
	Magnesite	—	51.8	47.2	64.3	—	27.2	24.8	16.7
	Mg + B	—	220.5	82.7	325.2*	—	53.7	31.9	41.9*
D	Control	25.4	52.7	35.7	—	15.7	27.1	21.5	—
	Borax	—	261.0	94.0	—	—	45.2	23.0	—
	Magnesite	—	48.7	29.1	—	—	24.2	20.1	—
	Mg + B	—	320.0	86.1	—	—	47.5	24.0	—
FY	Control	25.3	47.6	35.8	35.5	12.1	29.0	24.2	23.0
	Borax	—	368.0	73.7	78.3	—	57.0	27.9	23.5
	Magnesite	—	46.8	43.1	43.0	—	32.3	25.3	20.8
	Mg + B	—	337.0	73.2	70.1	—	54.8	27.4	25.0
R	Control	28.4	48.1	29.9	40.5	13.1	26.2	17.2	16.5
	Borax	—	192.0	76.8	80.4	—	43.3	23.4	23.6
	Magnesite	—	46.8	27.2	37.4	—	31.1	17.8	13.1
	Mg + B	—	253.5	72.3	81.8	—	40.7	22.8	25.5
FR	Control	23.4	57.6	34.3	50.0	15.4	30.3	21.2	23.2
	Borax	—	349.1	72.2	92.0	—	54.2	28.4	25.8
	Magnesite	—	131.7	44.2	46.7	—	39.3	23.7	26.6
	Mg + B	—	366.5	70.5	92.4	—	47.7	29.8	24.4

Dates of sampling: 2–10 March, 1950; 20–23 February, 1951; 4–7 March, 1952; 24 February–3 March, 1953.

*A second application of 1 oz. of borax per hill was given on 15 Oct., 1952, in Garden C, and on 7 Oct., 1952, in Garden FA.

deficiency in October-November, 1950, were gardens C and L, which have relatively high pH values, especially in the subsoil. Gardens D, R, and H showed no deficiency symptoms at this time. The others were affected to varying degrees; for example, some parts of garden G were severely affected with boron deficiency symptoms in the shoots. These field trials have been observed until the harvest time of 1953, samples of leaves and cones being obtained in each season 1951, 1952 and 1953 at picking time.

Results of boron determinations on samples from gardens on the granite-derived soils are given in Table V. Five of these are in the northern, and one in the southern part of the district. Data for samples obtained in 1950 before any treatments were begun are included. It is apparent that seasonal conditions caused appreciable variations in the boron contents of both leaves and cones on the untreated control plots. There is no consistent effect of the application of magnesite on the boron content of either the leaves or the cones, whether in the season of application, which was relatively dry, or in the succeeding seasons, both of which had very wet spring periods. In 1951 the boron contents of the leaves and cones were much higher than in 1950. In 1952, there was generally a fall in boron content of both leaves and cones as compared with 1951, but in 1953 the boron contents of the cones are similar generally to those for 1951, although the contents of the leaves varied somewhat between the two seasons. It may be of interest to remark that boron deficiency symptoms were seen in a few commercial gardens early in the 1952-53 season.

Remarkable increases in boron content of the leaves followed from the application of borax. The greatest increase was in Garden FY where the boron content of the leaves was raised from 48 to 368 p.p.m. Increase in boron content of the cones was appreciable also, the values of the control plots being nearly doubled by the use of borax. The highest value for the cones was 57 p.p.m., obtained in the garden where the high figure was reported in the leaves. In 1952, due to the heavy rains, leaching was probably appreciable, especially on the more sandy areas, so that the available boron of the soils was likely to be reduced somewhat. This is confirmed by the much lower values found for the boron content of leaves and cones on both untreated and treated areas. The lowest value for leaves from treated plots was at Garden C, on a medium sand, where the 1951 value of 325 p.p.m. was reduced to 56 p.p.m. On the other five areas the boron content of leaves from borax treated plots ranged from 72 to 102 p.p.m. Boron in the cones was only from 2 to 7 p.p.m. greater in the case of treated plots than in control ones, the latter ranging from 16 to 24 p.p.m. Seasonal conditions in 1952-53 have had very similar effects on the borax treated plots, causing appreciable increases over the values for 1952 in the leaves, but in some cases a further fall in the boron content of the cones has taken place. On the two gardens, C and FA, on the most sandy soils of the set further applications of 1 oz. of borax per hill were made in the spring of 1952. Very great increases in boron content of the leaves have followed, together with appreciable increases in the boron contents of the cones, almost as great as followed the original application in the 1950-51.

In no case has the effect of the magnesite been detrimental to the level of boron in either the leaves or the cones.

TABLE VI. BORON CONTENT (B), IN PARTS PER MILLION ON THE DRY BASIS, FOR HOP LEAVES AND CONES FROM HILLS TREATED WITH BORAX AND MAGNESITE FROM GARDENS ON SOILS OF THE MOTUPIKO SERIES

Garden	Treatment	Leaves				Cones			
		1950 (p.p.m.)	1951 (p.p.m.)	1952 (p.p.m.)	1953 (p.p.m.)	1950 (p.p.m.)	1951 (p.p.m.)	1952 (p.p.m.)	1953 (p.p.m.)
H	Control	41.2	70.1	56.7	—	23.7	26.7	21.8	—
	Borax	—	530.6	131.9	—	—	55.3	23.3	—
	Magnesite	—	76.3	53.3	—	—	32.0	19.8	—
	Mg + B	—	414.6	158.2	—	—	61.4	22.7	—
P	Control	36.0	44.3	20.2	86.0	18.8	28.4	18.0	27.4
	Borax	—	247.5	107.3	155.9	—	49.7	26.3	30.1
	Magnesite	—	43.7	18.6	85.9	—	27.1	18.0	29.7
	Mg + B	—	338.6	114.2	137.0	—	51.9	27.2	30.9
L	Control	29.8	30.7	44.7	32.2	14.6	22.2	25.7	19.4
	Borax	—	158.2	79.6	79.5	—	32.5	28.7	24.8
	Borax	76.7*	179.0†	134.9	138.4	26.9*	43.0†	31.0	25.0
G	Control	41.0	49.9	—	54.1	16.6	27.4	—	23.2
	Borax	—	302.8	—	102.8	—	55.8	—	28.4
	Magnesite	—	49.9	—	53.9	—	26.1	—	22.3
	Mg + B	—	336.7	—	110.8	—	52.2	—	32.0

Dates of sampling: 2–10 March, 1950; 20–23 February, 1951; 4–7 March, 1952; 24 February–3 March, 1953.

*Treated with ½ oz. of borax per hill in 1948.

†Treated with a further ½ oz. of borax per hill on 1 Nov., 1950.

Analytical data for the four experimental areas, two in the northern, and two in the southern, part of the hop growing area, on the Motupiko soils are given in Table VI. They confirm the data given for the Sherry and Riwaka soils in Table V. It is apparent, however, that on the heavier soils of these gardens the boron content of the leaves from the treated areas has been maintained better than on the more sandy soils of the granite-derived series; there is also an appreciable residual effect in raising the boron contents of the cones. Included in this set is one of the original areas treated with borax in 1948; this is in Garden L. New plots were set out in 1950, at which time the old area was re-treated. It is clear that on this doubly-treated area the boron content of the leaves has been maintained at a more uniform level than on the singly treated plots, but at the same time there has been no appreciable difference in the boron content of the cones on the two areas in 1952 and 1953. As in Table V, the use of magnesite has

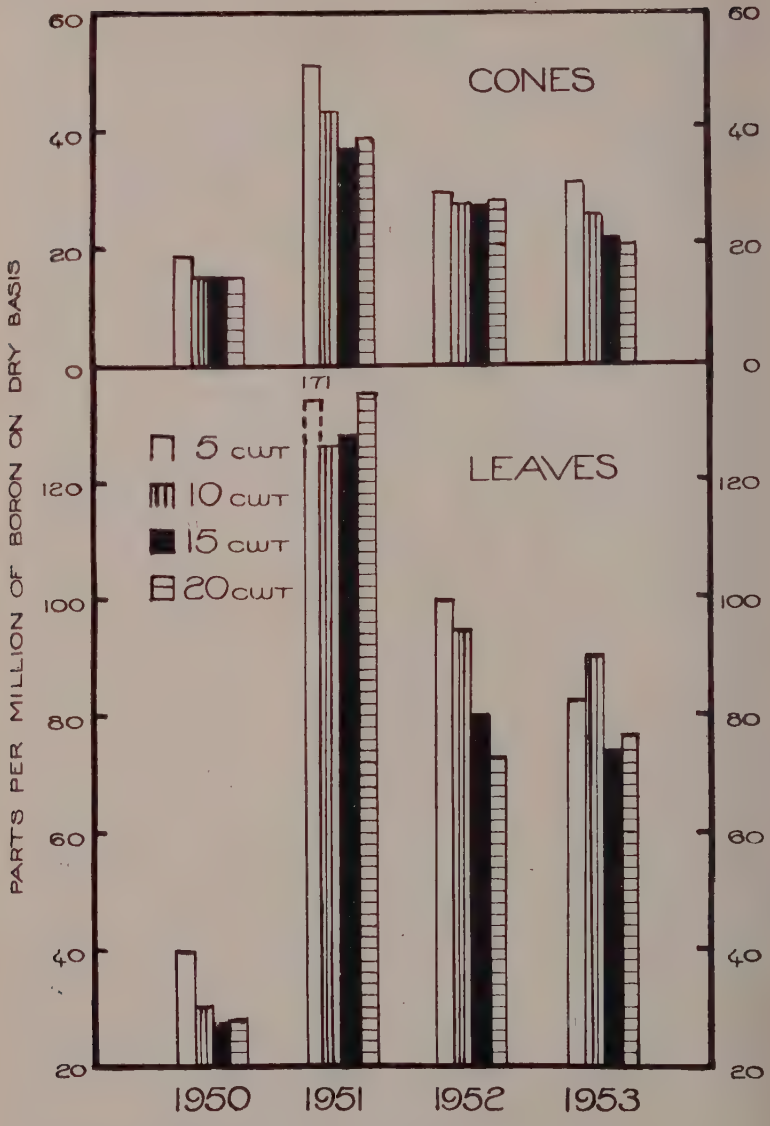


FIG. 8.—Effect of variation in rate of application of standard fertilizer on boron content of leaves and cones.

had no consistent effect on the intake of boron by the plants on the Motupiko soils.

Applications of borax were effective in controlling the untoward symptoms on the plants in gardens which had shown them. Throughout the district in commercial gardens, borax at the recommended rate

of ½ oz. per hill has given very satisfactory results. A few cases of toxic symptoms have been seen as a cream-coloured edging and incurling of the edges of the leaves, but these have occurred on weak plants or young replants when the borax has been used at a rate greater than that recommended, or in a manner other than as given above. No yield records are available for untreated and treated areas on either the experimental plots or commercial areas.

EFFECT OF FERTILIZERS ON BORON CONTENT OF LEAVES AND CONES

In one of the gardens on Motupiko fine sandy loam plots 5 hills × 4 hills have received a standard fertilizer mixture prepared from superphosphate, sulphate of potash, sulphate of ammonia and dried blood at the rates of 5 cwt., 10 cwt., 15 cwt. and 20 cwt. per acre for several years. The fertilizer has been placed about the hills and not broadcast. A topdressing of sulphate of ammonia at the rate of 1 cwt. per acre was given in each December. Although there is only one plot of each treatment the fact that they have been maintained for a number of years and sampled for boron determinations over four seasons makes any material and data obtained from them of interest. Sampling began at the harvest of 1950, before any borax had been applied. Before the next harvest, the hills had received ½ oz. of borax each. The boron contents of leaves and cones taken from near the tops of the plants are shown in Fig. 8. While it is possible that the plants may not have settled down completely to the varying rates of application of fertilizer, it is apparent that in 1950, except for the 5 cwt. rate, there is no essential difference in the boron contents of both leaves and cones for the varying amount of fertilizer used. In succeeding seasons, there is some evidence that as the rate of application of fertilizer increased, the boron content of both leaves and cones decreased. At no time, however, has the depression in boron intake been sufficient to reduce the levels of boron below those considered to be satisfactory for healthy growth.

The effect of an application of 2 tons of sulphate of potash per acre on boron intake was examined on plots replicated four times in seven gardens. These plots were set out by the Mycology Department of the Institute for another purpose. A complete set of samples from these plots was obtained only in 1950. As shown in Fig. 9, no consistent effect was noted on the boron content of either leaves or cones, whether the garden was on granite-derived soil (Gardens D and FR) or on Motupiko soil types (Gardens I, B, E, G and L).

Garden FR was sampled again in 1951 and Garden L in both 1951 and 1952. These gardens received borax applications at the standard rate of ½ oz. per hill in the spring of the 1950-51 season. The further data obtained, together with those for 1950, are presented in Table VII.

On the Riwaka silt loam the potash application has not affected the level of boron in either leaves or cones in both seasons; the difference between the figures for leaves in 1951 may not be beyond experimental error. On the Motupiko soil there are the usual decreases in boron content of both leaves and cones in the second year after application of the borax. In 1951, the boron content of the cones was the same for

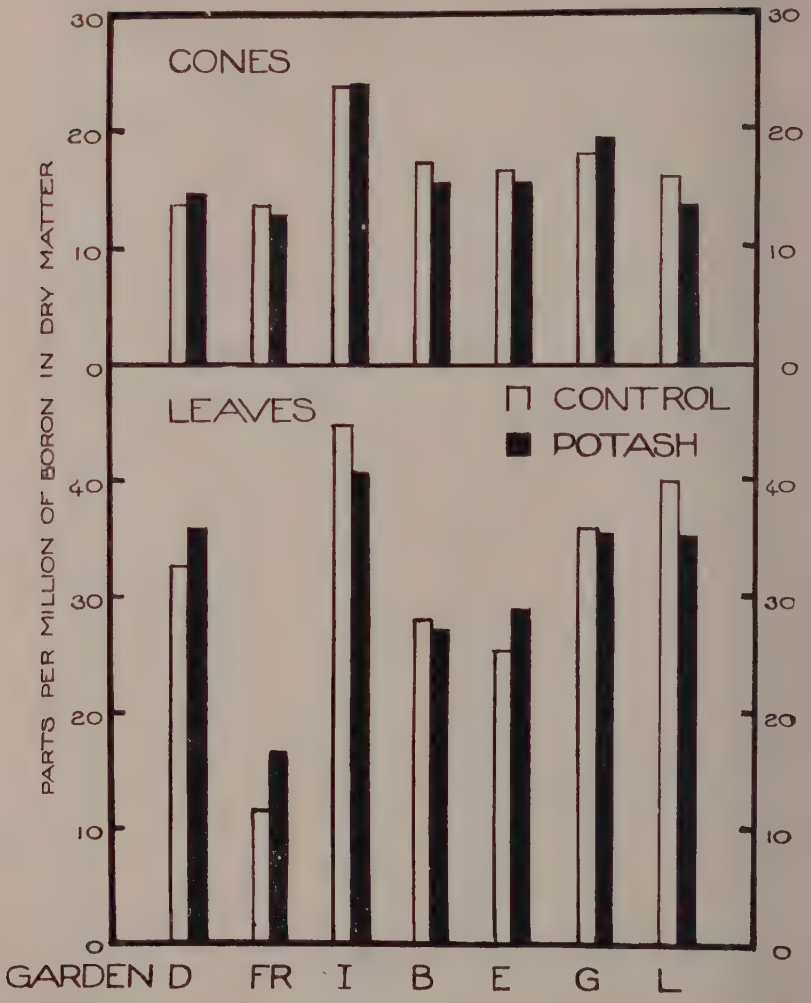


FIG. 9.—Effect of an application of 2 tons of sulphate of potash per acre on boron content of leaves and cones.

both treated and untreated plants, but the leaves from the potash-treated plots were appreciably richer in boron than the control material. This difference was repeated in 1952 to a less marked degree. A very striking increase in boron content of the potash-treated cones is shown in 1952. It is obvious that further data are required before a decision can be made on the effect of applications of sulphate of potash on the boron intake. A rate of 2 tons per acre of this fertilizer is not economic. It would appear likely that any influence of the smaller amounts of potash that may be added as a supplement to the usual applications of fertilizer would be unimportant.

TABLE VII. EFFECT OF AN APPLICATION OF 2 TONS OF SULPHATE OF POTASH PER ACRE ON THE BORON CONTENT OF HOP LEAVES AND CONES

(Boron expressed in parts per million in the dry matter)

Soil type	pH Value of soil	Season	Leaves		Cones	
			Control p.p.m.	Potash-treated p.p.m.	Control p.p.m.	Potash-treated p.p.m.
Riwaka	6.55	1950	11.6	16.7	13.7	12.9
silt loam		1951	105.6	94.3	33.8	33.1
Motupiko	6.45	1950	39.9	25.2	15.9	13.6
fine sandy		1951	122.8	159.0	42.8	42.9
loam		1952	87.6	101.2	13.6	29.9

INTAKE OF BORON BY DIFFERENT PARTS OF THE HOP PLANT

The data already presented have shown that the amounts of boron in the dry matter of the leaves and cones from given plants are by no means the same. A further inquiry into the distribution of boron in the plant and into the total intake on an acre basis is of considerable interest. Hop plants have been cut off at ground level and then separated into cones, main bine, lateral bines, leaves from main bine,

TABLE VIII. BORON CONTENTS OF DIFFERENT PARTS OF HOP PLANTS, AND INTAKE OF BORON PER ACRE

Treatment	Constituent	Cones	Main bine	Lateral bines	Leaves on main bine	Leaves on lateral bines	Totals and means
No Borax *	Dry Matter: lb./ac.	4241	927	1465	699	1032	8364
	Boron: p.p.m. in dry matter	12.9	8.0	12.8	23.2	19.1	14.0
	Boron: oz./ac.	0.88	0.12	0.30	0.26	0.32	1.88
Borax	Dry Matter: lb./ac.	3953	1143	1892	510	1781	9279
	Boron: p.p.m. in dry matter	25.0	12.7	14.8	88.5	57.6	31.1
	Boron: oz./ac.	1.58	0.23	0.45	0.72	1.64	4.62

*mean of two plants.

and leaves from lateral bines. These were weighed, dried and analysed for boron content. Data are given in Table VIII for the average results for two plants not receiving borax and for one plant that has been treated with borax. The latter, and one of the untreated plants, were examined in 1952 and the other untreated one in 1953.

Included in Table VIII are the yields of dry matter per acre, which with the data for boron content enable a calculation to be made of the uptake by the plant and the distribution of that boron among its constituent parts. No discussion will be given here on the dry matter data. Leaves from main bines are the richest in boron, followed closely, in the case of the no-borax plants, and less closely, with the borax-treated plant, by the leaves from the laterals. Next in order of richness in boron are the cones which in the plants sampled provided about half of the total dry matter of the plants. The lateral bines are slightly richer in boron than the more woody main bines. The weighted mean boron contents in both sets of data happen to be nearest to the cones in absolute value and are slightly greater in value than those for the cones. For the no-borax plants no part of the plant is more than 50 per cent lower, nor much more than 50 per cent greater in boron content, than the weighted mean value of 14.0 p.p.m.

Intake of boron per acre by the no-borax plants was 1.88 oz. of the element, corresponding to 1.0 lb. of hydrated borax. Of this amount nearly half was present in the cones; approximately 0.3 oz. per acre was in the leaves and lateral bines. Little more than 0.1 oz. per acre was in the main bines. In the borax-treated plant 1.58 oz. of boron, out of a total for the plant of 4.62 oz., was present in the cones. Leaves on the lateral bines contained nearly the same amount as the cones, while the leaves on the main bines accounted for 0.72 oz. of boron per acre. Lateral bines and main bines contained much smaller amounts of boron. The total intake of boron by the aerial portions of this plant corresponds to 2.6 lb. of borax per acre. In a hop garden, the only part of the plant which is removed each year from the area is the cones. As has been seen, the drain on the soil is not likely to be the equivalent of more than one or two pounds of borax per acre even by a very heavy crop. Assuming that an average crop will consist of 1,600 lb. per acre of dry cones with a boron content of 25 p.p.m., the removal per acre will be equivalent to only 5.5 oz. of borax.

Although roots were not sampled from the plants discussed in Table VIII, such material has been obtained from other plants. Boron contents have ranged from 8 to 17 p.p.m. in the dry matter. For a given plant there does not seem to be any great variation in boron content of the crown, or of upper and lower roots. Sufficient data have not been obtained to enable a statement to be made on any relationship between boron content of the crown and roots, and the incidence of boron deficiency symptoms in the leaves.

Discussion

The development of symptoms on the leaves places the hop plant in that group of plants where expression of boron deficiency is in the vegetative rather than in the fruiting part of the organism. To date no distinctive appearance of the cones that might be associated with a deficiency of boron has been seen.

It has not proved possible to set a limit for the amount of available boron in the soil above which the hop plant will be healthy and below which it will show symptoms of a deficiency. Thus in Table IV, Garden D with an available boron content of 0.31 p.p.m. and a pH value of the soil of 6.25, was healthy, but Garden L with corresponding figures of 0.30 p.p.m. and 6.5 was severely affected with boron deficiency symptoms; Garden FR with an available boron figure of 0.12 p.p.m. in the topsoil was not nearly so badly affected in the 1950-51 season as Garden C with 0.22 p.p.m. On the other hand the subsoil figure of 0.26 p.p.m. in FR may have been a compensating factor, but in C the available boron content was low throughout the depth of soil examined. Climatic conditions are the controlling factor in deciding whether deficiency symptoms will appear or not when the available boron in the soil is low. It was very noticeable in the 1950-51 season that many gardens showed little sign of boron deficiency trouble later in the season after very good growth had been encouraged by sufficient and well-distributed falls of rain. No symptoms were seen in 1951-52, but some gardens were affected in the spring and early summer of the 1952-53 season.

A further matter of interest, in view of the German experience quoted in the introduction to this paper [1, 2] is for how many years could a given soil be expected to supply boron for use by the hop plants. If it be assumed that the water-soluble (available) boron content of the soil is 0.5 p.p.m., then 1 lb. of boron would be available per 8-in. depth of soil per acre. Many of the fine roots ("fibre") will be in this section of the soil, but other roots, especially in a deep free soil, will go many feet into the ground. They may however be essentially suppliers of water rather than of nutrients. Assuming that the main supply of mineral nutrients comes from the top two feet of soil, then about 3 lb. of boron, the equivalent of 27 lb. of borax, will be available to the plant. In view of what has been said above, the whole of this boron may not be available by reason of climatic conditions making the boron less readily usable or by their effect on the root system making the plant less efficient as a gatherer of nutrients. Moreover, the water-soluble boron is only a fraction of the total boron of a soil. However, it is clear from the above calculation that there may be a supply of water-soluble boron theoretically sufficient to grow over fifty crops. It is known that some Nelson hop-gardens have been present on the same area for at least 80 years. In the absence of some additions of boron through the fertilizers that have been used, the available boron supply may thus have been seriously depleted. It is therefore not surprising that in some gardens on sandy soils the supply of boron may be approaching sub-optimal levels and that climatic conditions suitable for the development of boron deficiency symptoms may operate to bring about the expression of those symptoms. Whether there is any correlation between age of garden and susceptibility to boron deficiency in the Nelson area is not known.

ACKNOWLEDGMENTS

The authors wish to thank Messrs. E. Chittenden and G. Ward for assistance in collecting samples, and the latter for preparing them for analysis. The co-operation of the several growers who permitted the field trials to be carried out in their hop gardens is much appreciated.

References

1. Zatler, 1942: *Allg. Brau u. Hopfztg.*, 14 Mar., quoted by Hoed[6].
2. Linke, W., 1938: *Landw. Fachpr. Tschech. 16 (4)*: 17.
3. Dennis, A. C.; Dennis, R. W. G., 1939: *Fert. Feed. St. J., Vol. 24,* 8 and 22 Feb.; 8 and 22 Mar.; 5 and 19 Apr.
4. Doerell, —.: quoted by Hoed[6].
5. Bertrand, G., 1942: *Ann. Agron., 12*: 189.
6. Hoed, F., 1948: *Ann. Gembloux, 54*: 113.
7. Wye Coll. Dep. Hop. Res., 1951: *Ann. Rep.* 1950, p. 10.
8. Wye Coll. Dep. Hop Res., 1952: *Ann Rep.*, 1951, pp. 10, 22.
9. Schropp, W., 1950: *Zeitsch f. Pflanzenernäh., Düng., Bodenk., 51*: 127.
10. Askew, H. O.; Monk, R. J., 1951: *Nature, 167*: 1074. See also *Cawthron Inst., Ann. Rep.*, 1950-51, p. 10.
11. Askew, H. O.; Chittenden, E. T.; Monk, R. J., 1951: *J. Hort. Sci., 26*: 268.

EFFECTIVENESS OF COBALT SULPHATE APPLIED TO COBALT-DEFICIENT PUMICE LAND FROM THE AIR

By E. D. Andrews, Animal Research Station, Department of Agriculture, Wallaceville

(Received for publication, 10 August 1953)

Summary

Cobalt-deficient pumice land aerially topdressed with a solution of cobalt sulphate to give a calculated rate of 20 oz. of the hydrated salt per acre remained healthy for approximately three years.

Introduction

Following reports[1, 2, 3] of the successful use of cobalt in Australia, New Zealand investigations have shown that bush sickness, a wasting disease of cattle and sheep, is due to a deficiency of cobalt in soils[4] and pastures[5, 6] and that the ailment can be successfully controlled by topdressing deficient land with cobalt salts[7, 8]. In South Island trials[9] conducted on cobalt-deficient granite soils, topdressing with a cobalt equivalent of 4 oz. and 8 oz. hydrated cobalt sulphate ($CoSO_4.7H_2O$) per acre enabled wethers to be carried satisfactorily for two seasons. After one year the heavier dressing gave a better result both in respect of live-weight increase and wool yield. From this it was concluded that optimal results would be obtained from at least 4 oz. per acre or 8 oz. if the dressing was required to be effective over two seasons. North Island experiments[10] on cobalt-deficient pumice soils showed that the cobalt content of pastures topdressed initially at the rate of 5 oz. per acre remained above deficiency levels for periods ranging from six to nine months. However, trials in which repeated 5-oz. applications were made to cobalt-deficient pastures which had at some time previously been cobalt-topdressed indicated that satisfactory cobalt levels could be maintained for periods ranging from nine to twelve months. Sheep grazing pastures topdressed at the rate of 5 oz. per acre remained healthy for at least one year. The use of superphosphate as a cobalt carrier has been investigated[11] and found satisfactory[12]. On the basis of the above findings it has been recommended[13] that annual applications of 5 oz. cobalt sulphate per acre to cobalt-deficient country are satisfactory, and that the equivalent of this amount can conveniently be incorporated in superphosphate. At the same time it has been emphasized that topdressings at the rate of 5 oz. per acre may not remain fully effective for more than one season and that annual applications should be made to ensure control of cobalt deficiency disease.

Although the effectiveness of heavier dressings has been investigated, results have shown little uniformity and some anomalies. Consequently it has not been possible to formulate general recommendations based on the findings. In South Island trials one application of 16 oz. as cobaltised superphosphate to cobalt-deficient pasture maintained wethers healthy for more

than five seasons. From North Island sheep experiments supported by pasture analyses it was concluded[10] that the result from 10 oz. per acre was not appreciably better than from 5 oz., but on the other hand the cobalt content of pastures and the health of sheep in paddocks topdressed with 20 oz. and 40 oz. cobalt sulphate per acre remained satisfactory for more than six years.

In New Zealand the topdressing of cobalt-deficient land with cobaltised superphosphate has now become common practice. The method is readily applicable where machinery can be employed, but only within very recent years has it become possible to apply superphosphate (and hence cobaltised superphosphate) to inaccessible blocks of land and broken hill country by means of aircraft[14, 15]. Prior to the development of aerial topdressing of superphosphate, successful trials had been carried out on the sowing of lupin seed[16], and the topdressing of copper-deficient peat land with bluestone[17] from the air. This earlier work indicated that aircraft should be suitable for the distribution of cobalt salts also. In particular the use of aircraft would avoid the difficulties imposed by hilly or otherwise inaccessible country. The primary objects of an aerial cobalt-topdressing trial would be twofold. Firstly it was desired to demonstrate that aerial topdressing of cobalt was technically possible and economically feasible. Secondly, assuming a successful and reasonably even spread, it was desired to determine for what length of time the applied cobalt would maintain the cobalt content of pastures on cobalt-deficient land above deficiency levels. It was therefore proposed to topdress with a solution of cobalt sulphate to give a calculated rate of 20 oz. of the hydrated salt per acre. This figure was chosen because, as already indicated, previous trials with dressings of that order had given protection against deficiency for a proportionately longer period than the lower rates of 5 oz. and 10 oz. per acre.

An area suitable for aerial topdressing was available near Waimiha, some 23 miles north of Taumarunui and east of the Ongarue River. The farm was situated within a high rainfall belt (60–100 in. per annum), the prevailing wind being north-westerly. Access was difficult and the country largely hilly, with many steep faces cut by streams with a general flow from east to west. Sufficient easy-rolling and flat land was, however, available to offer varied experience in the technique of aerial spreading. Because of the nature of the country, normal topdressing procedures had not been practicable.

Soils which had developed under dense podocarp forest were derived essentially from a subaerially deposited volcanic ash classified as the Taupo shower[18]. The ash is rhyolitic in composition, contains a large proportion of pumice, and its coarse texture allows of free drainage. As might be expected from the topography of the farm, soils varied greatly in depth. As a result of water sorting, the easy-rolling country contained within the basin of the Ongarue River, and flats and terraces formed by the smaller streams were associated with pumice layers, in some parts many feet in thickness. On the higher country, thin pumiceous soils gave way in places to outcrops of bare rhyolite rock and, occasionally, weathered greywacke.

Following a bush-burn some 30 years previously, the land was sown down with a mixture consisting of suckling clover, white clover, lotus major and perennial ryegrass, but within a few years the perennial ryegrass and most of the white clover had disappeared. By 1947, the pastures consisted essentially of danthonia, sweet vernal, browntop, yorkshire fog, lotus major, some white clover and flat weeds. On those parts where stock had camped, subterranean clover was also in evidence, and it is surmised that this clover had been introduced by cattle over the years. Part of the pastures had reverted to bracken fern and manuka and there had been considerable encroachment by piripiri and ragwort. The total area of the holding was 2,700 acres, and of this some 2,000 acres was in pasture, the rest consisting of native bush and scrub. At the time when aerial topdressing was contemplated the current owners had been in occupation for about two years and marked improvements, including progress in the clearing of second growth, had been effected. Stock consisted of approximately 1,100 sheep and 200 head of cattle.

The cobalt-deficient nature of the farm was established from the following data:

(1) Grange and Taylor[18] have identified Taupo ash soils as being closely associated with bush sickness.

Kidson[4], from the analyses of fourteen different samples, showed that these soils are low in cobalt with a range of 1.0 to 1.8 parts per million (p.p.m.) and an average of 1.4 p.p.m.

Extensive investigations into the cobalt content of North Island pastures have shown that Taupo ash soils are invariably associated with low-cobalt pastures[6], and that the cobalt content remains at deficiency levels throughout the season[19].

(2) The farm had a previous history of stock unthriftiness and mortality. The use of licks containing limonite and, later, cobalt, had apparently relieved the condition. Moreover, nearby holdings had previously been affected by bush sickness and good response to cobalt topdressing had been claimed.

(3) Analyses of pasture samples obtained from the farm prior to topdressing revealed a low cobalt content (Table I).

In planning the aerial topdressing experiment, five separate blocks of land were chosen bounded by straight or regularly-curving lines. The total area involved was 1,800 acres which thus included nearly all the pasture land.

Topdressing was carried out during August, 1947. It was judged that a reasonably even and accurate spread had resulted and virtually all of the cobalt appeared to be deposited within the selected blocks, although owing to the size of the blocks and the rugged nature of the country, it was possible for ground observers to check only a part of the operation. Nevertheless, on only one occasion was there a visible loss outside a boundary. It was concluded that the experiment showed that cobalt sulphate could be successfully and economically distributed from the air.

Preparation of the cobalt solution, measurement of spread, ground organisation and flying technique have been described, and effectiveness of operation discussed, in a previous publication[20]. Determination of the length of time during which aerial topdressing remained effective in maintaining the cobalt content of pastures above deficiency levels forms the subject-matter of the present paper.

Experimental Procedure

Sampling sites, roughly an acre in area, were chosen so as to be as representative as possible of the varying kinds of terrain within each topdressed block, and from these pasture samples were collected at intervals for cobalt analyses. For comparison, samples were also taken from a "non-topdressed" area adjoining one of the topdressed blocks. It was not possible to sample extensively outside the prescribed blocks since the farm was largely surrounded by heavy bush and scrub. The state of pastures varied greatly from time to time and from place to place. In spring and summer, grass tended generally to be much longer than during the winter months. At times growth was exceptionally rank in paddocks which had been shut up for a period, whereas in other heavily-stocked paddocks pastures were well eaten down. Where grass was short and subjected to trampling by stock, risk of soil contamination would be greater. As discussed later this was probably of little consequence except for samples collected within the thirteen months following topdressing.

Duplicate cobalt determinations were carried out on each sample using a slight modification of the Nitroso-R salt method as described by McNaught[21]. In the analyses of earlier samples a photoelectric colorimeter constructed at Wallaceville was employed; later, this was replaced by a Beckman Model D.U. Spectrophotometer carrying 5-cm. absorption cells.

Other work[6, 22, 23] has indicated that fodders containing on an average less than 0.07 p.p.m. of cobalt on a dry-weight basis throughout the season are likely to be unhealthy for sheep, while 0.07 to 0.10 p.p.m. may be considered to be marginal[23]. For the purpose of the present paper, 0.07 p.p.m. is defined as the "critical level" of cobalt in pasture. The length of time taken for the cobalt content of pastures to fall below the "critical level" is adopted as a measure of the period during which aerial topdressing remained effective.

Results

In Table I is shown the cobalt content of pasture samples taken from various places on the farm prior to topdressing.

It is evident that all samples were low in cobalt content irrespective of the nature of the terrain from which they were taken.

Table II shows the cobalt content of pasture samples taken from differing kinds of terrain at intervals after top-dressing.

TABLE I. COBALT CONTENT OF PASTURES PRIOR TO TOPDRESSING

(Cobalt expressed as parts per million on dry weights)

Nature of Terrain	Co. (p.p.m.)
Flat	0.04
Flat	0.06
Flat	0.04
Easy-rolling	0.01
Steep slopes facing north and south	0.04
Average	0.05

Fig. 1 shows averaged results from January, 1948, to the end of October, 1951, and enables comparisons to be readily made with the "critical level" for the cobalt content of pasture, and with results for samples from the "non-topdressed" area. Higher figures for the first two samplings from the latter would suggest some contamination by extraneous cobalt. This is feasible since the "non-topdressed" area was contiguous with a topdressed block, and could have received some cobalt solution as fine spray during topdressing.

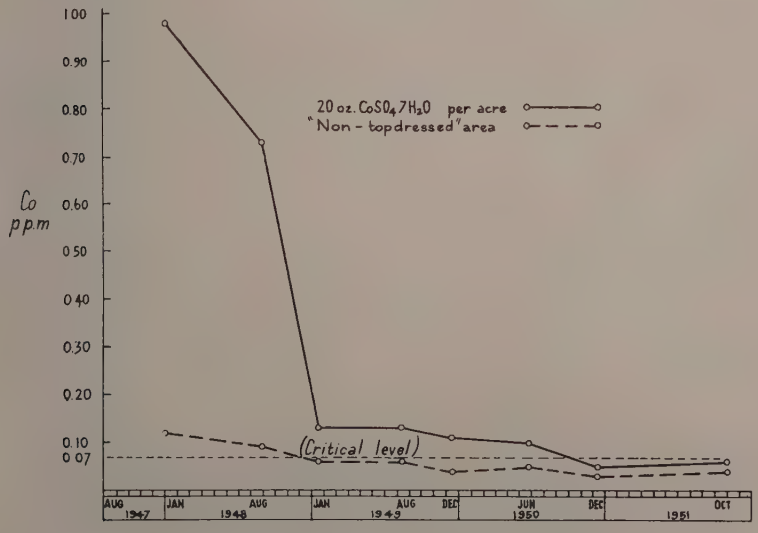


FIG. 1.—Cobalt content of pastures.

TABLE II. COBALT CONTENT OF PASTURES AERIALLY TOPDRESSED DURING AUGUST 1947.
(Cobalt expressed as parts per million on dry weights)

Nature of Terrain	Sampling Site No.	DATES OF SAMPLING							
		6/1/48	31/8/48	18/1/49	9/8/49	13/12/49	25/6/50	18/12/50	31/10/51
Flat	1.	3.72	2.91	0.08	0.13	0.09	0.05	0.05	0.05
	2.	0.71	0.14	0.12	0.18	0.12	0.19	0.07	0.05
	3.	0.17	0.19	0.17	0.10	0.10	0.12	0.06	0.09
	4.	1.04	0.24	0.17	0.09	0.08	0.12	0.04	0.05
	5.	0.56	—	0.13	0.12	0.10	0.11	0.10	0.07
Easy-rolling	6.	0.34	0.89	0.10	0.24	0.17	0.10	0.05	0.06
	7.	0.30	0.68	0.10	0.13	0.18	0.09	0.05	0.06
	8.	0.70	1.21	0.09	0.10	0.12	0.06	0.05	0.06
	9.	0.36	0.39	0.07	0.14	0.08	0.11	0.06	0.05
Moderate to steep slopes facing north	10.	1.81	0.58	0.10	0.16	0.11	0.15	0.04	0.05
	11.	0.33	0.38	0.12	0.08	0.06	0.12	0.03	0.05
	12.	0.53	0.66	0.10	0.08	0.08	0.07	0.04	0.04
	13.	0.42	—	0.14	0.12	0.11	0.10	0.04	0.05
Moderate to steep slopes facing south	14.	2.60	0.45	0.13	0.14	0.13	—	0.03	0.06
	15.	0.94	—	0.26	0.17	0.09	0.11	0.04	0.05
Steep slope facing east	16.	0.46	0.22	0.19	—	—	—	—	—
Hilltops	17.	—	—	0.08	0.09	0.09	—	0.03	0.05
	18.	1.19	—	0.16	0.13	0.07	0.13	0.04	0.05
Averages*		0.98	0.73	0.13	0.13	0.11	0.10	0.05	0.06
"Non-topdressed" area		0.12	0.09	0.06	0.06	0.04	0.05	0.03	0.04

NOTES.—Blank spaces indicate that the sites were not sampled at the dates shown usually because pastures were very short. In the case of Site 16 the area had reverted to fern by 9.8.49.

*In the computation of averages, figures for Sites 16 and 17 have been omitted as most of the missing values occur within these series.

Discussion

Soil Contamination

It may be presumed that all pasture plants will be contaminated to a greater or less degree with soil and that this will be consumed by the grazing animal. McNaught and Paul[19] state that in bush-sick areas soils may contain from ten to forty times the concentration of cobalt found in dry pasture, and that availability to the animal of soil cobalt is probably very variable according to the type of soil. Consequently, interpretation in terms of animal health of results from the analyses of pastures for cobalt content is complicated to an extent dependant upon the degree to which the sample taken represents the pasture consumed by stock, the amount of soil contamination, the total cobalt content of the contaminating soil, and availability to the animal of soil cobalt as compared with pasture cobalt. Despite these difficulties it has been shown[6, 24] that in general good correlation can be established between the incidence of cobalt deficiency disease and results from pasture analyses provided care is exercised in keeping soil contamination of samples to a minimum.

When soil cobalt is low, there is little danger of the level of the cobalt content of the pasture being appreciably raised by soil contamination. For example, contamination with 1 per cent of a soil containing 1 p.p.m. would increase the pasture cobalt figure by only 0.01 p.p.m. After cobalt topdressing, however, the surface of the soil would for a time be rich in cobalt so that the effect of soil contamination could be serious. For example, the cobalt figure for a pasture contaminated with 1 per cent of soil containing 50 p.p.m. would be increased by 0.5 p.p.m. Furthermore, most of the topdressed cobalt would be deposited first on the leaves of pasture plants. Until such time as the original sward was replaced by new growth, or the adherent cobalt washed by rain from the grass to the soil, very gross errors in estimating the true cobalt content of pastures could result. Only 0.001 per cent of cobalt sulphate would be required to raise the pasture cobalt figures by more than 2 p.p.m.

Contamination offers a probable explanation for the high average results shown in Table II for samples from topdressed blocks at the first and second dates of sampling, and the wide ranges shown between individual figures for samples taken on these dates could be due, at least in part, to differences in the amount of contamination. Comparison of results for 31/8/48 against corresponding figures for 6/1/48 show in some cases a reversal of expected downward trends. These anomalies can be best explained as due to greater contamination of pastures with cobalt-enriched soil at the later date when short growth due to winter conditions combined with heavy stocking in some paddocks would render the collection of clean samples difficult. Table II shows that after 31/8/48 cobalt figures fell sharply to normal levels, and thereafter much more uniformity is evident for results given at each sampling date. It seems probable that by 18/1/49,

applied cobalt had disappeared from the leaves of pasture plants and the surface of the soil, and it is considered that from this date results are reasonably indicative of the cobalt actually contained within the pasture.

Effectiveness of Topdressing

It was considered possible that slope and orientation of the terrain, and thickness of pumice deposits might have some influence on the length of time during which topdressing remained effective. No definite relationships can, however, be traced from present results.

Detailed examination of Table II shows that for Sites 1 and 8 the cobalt content of pastures fell below the "critical level" at some time between two and three years after topdressing. In one doubtful case (Site 11), applied cobalt may have disappeared by the end of two years. The cobalt status of pastures from Sites 3 and 5 may have remained healthy for as long as four years. The cobalt content of pastures from Site 2 had reached the "critical level" by December, 1950, but was low in October, 1951. For the remainder of the sampling sites for which results are complete, it is clear that the cobalt content of pastures fell below the "critical level" between June and December, 1950, and that ten months later cobalt levels were still low. In Fig. 1 the curve joining the points for averaged results from topdressed areas cuts that for the "critical level" at October, 1950, and by December, 1950, has approached the value shown for the "non-topdressed" area. These results are interpreted as showing that, in general, aerial topdressing at the rate of 20 oz. per acre remained effective for approximately three years.

By chance, confirmation has been afforded from observations on stock health. When the farm was last visited by the writer in October, 1951, it was noticed that a large number of ewes appeared to be in an emaciated and weakened condition. On enquiry it was stated that obvious unthriftiness had developed by June, 1951. Some fifty animals had since died. Although the owners had previously been informed that results for the samples taken on 18/12/50 showed that the cobalt status of pastures was no longer satisfactory, no cobalt in any form had been used since the original topdressing was applied in August, 1947. A liver obtained from the farm in May, 1951, had shown a low cobalt content, 0.04 p.p.m. The owners were advised that a cobaltised lick should be provided on the hill country, and where feasible the more accessible land should be topdressed with cobaltised superphosphate. As an immediate measure, all sheep should be dosed with a cobalt-containing solution. In March, 1952, it was reported that four ewes left undosed as controls had died. The remainder had steadily improved. Lambs which had apparently not been dosed until after weaning had deteriorated seriously in condition, but thereafter had "benefited markedly" from cobalt dosing. There seems little doubt that relatively severe cobalt deficiency had developed by the middle of 1951, that is, nearly four years after

aerial topdressing. In the present instance it is probable that early signs of unthriftiness had passed unnoticed so that no accurate estimate of the time of onset of deficiency is possible. However, since animals were apparently healthy at the time of the writer's previous visit to the farm in December, 1950, it is concluded that topdressing had maintained the health of sheep for a period of more than three and less than four years, a finding which accords well with the analytical evidence.

Reference has been made to South Island experiments which showed that on a granite soil a 16 oz. per acre application maintained sheep healthy for five seasons, and to a trial conducted on a pumice soil in the North Island where the cobalt status in a paddock topdressed at the rate of 20 oz. per acre remained satisfactory for more than six years. In each case this represented a more economical use of cobalt sulphate as a topdressing than annual applications of 5 oz. per acre. Results from the present work were different; there was no advantage in period of effectiveness from a single application of 20 oz. per acre over what would be expected from 5 oz. annual applications. The writer believes that the latter results are more likely to represent the circumstances which would obtain on most cobalt-deficient country. A single application of 20 oz. cobalt sulphate will be more economical in spreading costs, but will not control cobalt deficiency in stock for any longer than four annual applications of 5 oz. per acre.

Acknowledgments

The writer is indebted to Mr. S. G. Stainton, Fields Instructor, Department of Agriculture, formerly of Taumarunui, for a description of the plant coverage of the farm; to Officers of the Soil Bureau, Department of Scientific and Industrial Research, Wellington, for discussions on the nature of the soil; and to Mr. B. J. Stephenson of the Wallaceville Animal Research Station staff for preliminary preparation of most of the samples for analysis.

References

1. Underwood, E. J.; Filmer, J. F., 1935: *Aust. Vet. J., 11*: 84-92.
2. Marston, H. R., 1935: *Aust. Coun. Sci. Industr. Res. J., 8*: 111-6.
3. Lines, E. W., 1935: *Aust. Coun. Sci. Industr. Res. J., 8*: 117-9.
4. Kidson, E. B., 1937: *N.Z. J. Sci. Tech. 18*: 694-707.
5. Askew, H. O.; Dixon, J. K., 1937: *N.Z. J. Sci. Tech. 19*: 317-25.
6. McNaught, K. J., 1938: *N.Z. J. Sci. Tech. 20*: 14A-30A.
7. Askew, H. O.; Dixon, J. K., 1936: *N.Z. J. Sci. Tech. 18*: 73-9.
8. Hopkirk, C. S. M., 1937: *N.Z. J. Agric. 54*: 344-9.

9. Askew, H. O., 1946: *N.Z. J. Sci. Tech. A28*: 37-43.

10. Filmer, J. F.: Pers. comm.

11. Askew, H. O.; Rigg, T.; Stanton, D. J., 1938: *N.Z. J. Sci. Tech. 20*: 82A-9A.

12. Maunsell, P. W.; Simpson, J. E. V., 1944: *N.Z. J. Sci. Tech. A26*: 142-5.

13. N.Z. Dep. of Agric. and Cawthron Inst., 1944: *N.Z. Dep. Agric. Bull. 180*: 6.

14. Campbell, D. A., 1948: *N.Z. J. Sci. Tech. 30A*: 65-77.

15. Greenall, A. F.; Quill, S. G.; Stephenson, J., 1951: *N.Z. J. Sci. Tech. A33*: 54-68.

16. Pritchard, A. M., 1945: *N.Z. J. Agric. 70*: 117-20.

17. Anderson, O. J. C.; Cunningham, I. J., 1946: *N.Z. J. Agric. 73*: 193-7.

18. Grange, L. I.; Taylor, N. H., 1932: *N.Z. Dep. Sci. Industr. Res. Bull. 32* (Part IIA): 21-51.

19. McNaught, K. J.; Paul, G. W., 1939: *N.Z. J. Sci. Tech. 21*: 95B-101B.

20. Andrews, E. D.; Pritchard, A. M., 1947: *N.Z. J. Agric. 75*: 501-6.

21. McNaught, K. J., 1948: *N.Z. J. Sci. Tech. A30*: 109-15.

22. Beeson, K. C., 1950: *U.S. Dep. Agric. Inf. Bull. 7*: 26-8.

23. Marston, H. R., 1952: *Physiol. Rev. 32*: 69.

24. Stanton, D. J.; Kidson, E. B., 1939: *N.Z. J. Sci. Tech. 21*: 65B-76B.

EFFECT OF SOIL ACIDITY ON GROWTH OF PASTURE PLANTS

I. POT EXPERIMENTS WITH GRASSES AND CLOVERS IN ACIDIFIED SOILS*

By A. J. McNeur, Grasslands Division, Department of Scientific and Industrial Research, Palmerston North

(Received for publication, 1 September 1953)

Summary

A number of species and strains of pasture plants were grown in a soil brought to the following levels of acidity: pH 7.20, 6.75, 5.95, 4.50 and 3.60.

The grass species showed only slight response to the varying acidities, but two species and the grasses as a whole did give significant trends in their response curves, their optimum acidity in each case being at a strongly acid level.

Total grass production was low, almost certainly owing to the early exhaustion of nitrogen supply.

The clover species grew well and showed definite reactions to the different acidity levels, many yield differences for each species being highly significant. The calculated optimum acidity for the white clovers was at a lower pH than for the red clover.

The weight of roots of the grasses increased irregularly in the more acid soils, while the weight of the red-clover roots decreased sharply as the acidity increased.

There was no obvious relationship between root weight and herbage yield in either grasses or clovers.

The acidities of the soils changed during the trial, the final acidity of the grass soils being on the whole very different from those of the clover soils.

Introduction

There is general agreement that the acidity of a soil plays a major part in determining the type of plant growing thereon[1]. Different explanations of the cause of the detrimental effects of excess soil acidity on plant growth have been advanced, but the majority have followed the early lead of Whitney and Cameron[2], in attributing the poor growth to toxic substances that arise owing to the extra solubility of certain elements such as iron[3], aluminium[4, 5, 6], manganese[6, 7, 8], and copper[9] under conditions of high acidity. Other workers, however, point out that nutrient deficiency, rather than elemental toxicity, may cause plant symptoms in soils of different acidity[10, 11, 12, 13]. Thus, under acid conditions calcium, phosphorus, molybdenum and potash may be deficient, while at near neutral or alkaline levels manganese, zinc, copper, and iron deficiencies may affect plant health[9, 13]. For these reasons, Truog[12] states that a pH of 6.5 is most likely to be suitable for optimum nutrient availability. Albrecht[14, 15] stresses the importance of calcium deficiency in acid soils and even states "the so called plant injury by soil acidity is largely a matter of deficiency of the plant nutrient calcium". Fried and Peech[16], on

*Much of the material included here was part of a thesis presented for M.Agr.Sc. in 1947.

finding that gypsum did not improve plant growth on acid soils as well as did lime, decided that calcium deficiency in the plant may be due to its inability to utilise the calcium from the acid soil even though it was present in adequate amounts as a soluble salt.

Apart from these factors of nutrition deficiency and elemental toxicity, workers record that acidity in itself exercises some direct effect on plant growth[17, 18, 3]. When working with natural soils there are so many inter-related factors playing a part that it is difficult to separate the effects of hydrogen-ion concentration from resultant elemental deficiency or toxicity, or from attendant biological results, and in order to throw light on the problem many workers have used water cultures where some of the important factors can be seperated and studied alone. Using this method Arnon and Johnson[19] in a comprehensive experiment found complete plant failure at extremes of acidity or alkalinity—pH 3 and pH 9—while the acidities between pH 4.0 and pH 8.0 were well tolerated by plants provided an adequate supply of nutrients was maintained. Other workers, such as Guest and Chapman[20], Duggar[21], and Hewitt[9] agree with this in effect as a result of their experiments using various plant species. From experiments using water cultures as well as soils it has been observed that when the nutrient level is held constant and the pH altered, most plants have a definite optimum acidity level at which maximum growth can be obtained. Tarr and Noble[22], Powers[23], Pizer[24], Salter and McIlvane[25], Arrhenius[26], etc., list numerous plants with the acidity levels which have been optimum for their growth. One interesting example of optimum acidity level among pasture plants is given by Lundegardh[18] who reports Olsen as finding *Deschampsia flexuosa* in the field only in soil of below pH 4.9, while *Deschampsia caespitosa* was recorded only in soils of above pH 5.0. Thus, Lundegardh, in reviewing work of Arrhenius, Stark and Olsen, concludes that different plant species (and even different strains within a species) have clearly defined optimum pHs for growth.

In order to facilitate research into soil acidity, a number of workers have used soil made acid by artificial means. Some have used iron sulphate or aluminium sulphate for this purpose[4], but sulphur[27, 28, 29] or sulphuric acid is more commonly used[30, 31]. Hydrochloric acid and phosphoric acid have also been used for the same purpose by Reid[32] and Lundegardh[18] but they agree that these do not appear as satisfactory as sulphuric acid for general use, owing to various growth irregularities.

In any study of soil acidity care must be taken when comparing pH figures taken at different times of the year. Minor changes of acidity occur with alteration in mosture content[33] but the main fluctuation is seasonal[34, 25]. Lutz and Chandler[34] report Nehring as recording that the highest pH values are found in winter and the lowest in summer, and that variations between these two extremes might be as great as 0.8 pH. This is in agreement with observations by the present author[35] where the acidity of untreated soil in the 0–3-in. layer in two successive winters (July) was pH 5.5, while in the same plot the recording in the January between

these went as low as pH 4.7. This would indicate that a comparison of two isolated pH figures recorded at different times of the year should be interpreted with care.

The present trial was designed to determine the effect of soil acidity on the growth of some of New Zealand's main pasture plants. In some species two strains or varieties were included to see if they reacted similarly to the various levels of soil acidity.

Experimental Methods

(a) *Soil and Treatments*: The soil used in this experiment was from land which had been cleared from scrub and bush five years before, sown to pasture and then exposed to open grazing. No fertiliser had been used on the area. The soil was mixed with clean washed sand in the ratio of one part sand to three parts soil, so that the mixture would be suitable for handling without structural damage, then sterilised by steam at 210° F for fifteen minutes to destroy any viable seeds.

For the acidification, mixed soil (8 lb.) was placed in eight-inch porous clay pots with the hole plugged, and saturated with an excess of sulphuric acid (1½ litres per pot), the strength being altered as required to produce the desired acidity levels. The appropriate strengths had been found from pilot trials and the following were used:

> Treatment N (neutral), tapwater; Treatment S (slightly acid), 0.25N acid; Treatment M (mediumly acid), 0.1N and; Treatment U (very acid), 0.2N acid; Treatment X (extremely acid), 0.4N acid.

After a period of twenty-four hours the drainage plugs were removed, the excess acid drained and the soils left for a week. After this time the pots were watered heavily every day for a few weeks to ensure adequate leaching. When the soils were dry enough to handle, the replicates for each treatment were thoroughly mixed, replaced in the pots, and allowed to stand some weeks before planting. The following were the five levels of soil acidity obtained from these treatments:

N, pH 7.2; S, pH 6.75; M, pH 5.95; V, pH 4.5; X, pH 3.6.

(b) *Planting*: To obtain the required number of plants 50 cuttings were taken from one plant of each species and these were rooted in sterilised soil. At a later stage 25 cuttings of each species were selected for uniformity to give five replications of each treatment.

(c) *Management*: The pots were held in metal trays each of which contained pots at the same acidity level, and water was added to these trays as required to provide adequate moisture for plant growth. Plants were cut and the herbage weighed whenever most of the treatments were at 4–6 in. height. Yields were recorded for twelve months from planting.

The following plants were used:

SPECIES	STRAIN OR VARIETY	CODE
Lolium perenne (perennial ryegrass)	Type 1 (good type)	Per. 1
Lolium perenne „ „	Type 3 (poor type)	Per. 2
Lolium multiflorum (Italian ryegrass)	Pedigree	It.
Lolium multiflorum x perenne derivative (short rotation ryegrass)	Pedigree	S.r.
Dactylis glomerata (cocksfoot)	N.Z. selection	Co.N.Z.
Dactylis glomerata „	Danish type	Co.D.
Trifolium pratense (red clover)	Cowgrass (early)	Red C.
Trifolium pratense „ „	Montgomery (late)	Red M.
Trifolium repens (white clover)	Type 1 (good type)	Wh. 1
Trifolium repens „ „	Type 2 (poorer type)	Wh. 2

(d) *Soil Acidity Determinations*: The soil acidity of each treatment was measured using the glass electrode at the start of the experiment, after six months, and at the conclusion of the trial twelve months after planting. For the initial and final determinations the treatment soils were well mixed before sampling, but for the intermediate checking soil was removed from the pots without disturbing the growing plants more than necessary.

(e) *Total Exchangeable Bases in Soil*: A measurement of total bases in the prepared soils was made only at the start of the trial. The bases were displaced by the "ammonium acetate" method[63] and "total exchangeable bases" determined on the leachate by the method of Bray and Willite[37].

(f) *Acid Soluble Phosphate in Soils*: The method of Burd and Murphy[38] was used to measure the acid soluble phosphate present in each soil treatment at the start of the trial.

RESULTS AND DISCUSSION

A. Herbage yields from individual species

(a) *Grasses*: The yields of herbage from grasses growing at the various acidity levels are recorded in Table I.

The yields from all the grass plants were very low, most of the weight being obtained within the first six months from planting; after this time growth became very slow indeed. From the plant colour and growth in the latter half of the trial at least, it was concluded that nitrogen deficiency was severely limiting grass growth and this may have had an effect on the reaction of plants to the soil treatments. At the time of the trial no means was known of correcting nitrogen deficiency without altering soil acidity, but it is possible that urea sprays might have assisted materially in improving nitrogen nutrition[39]. The statistical analysis of the grass yields is summarised in Table II.

TABLE I. AVERAGE YIELD OF GRASSES PER PLANT
(grams dry matter in 12 months)

Series	TREATMENTS					Total
	N	S	M	V	X	
Per. 1	8.9	8.9	8.7	9.2	8.8	44.5
Per. 3	8.1	8.9	11.6	11.5	7.5	47.6
It.	19.1	22.7	22.8	23.9	18.9	107.4
S. r.	14.2	16.8	12.3	14.6	13.3	71.2
Co. N.Z.	6.9	5.9	7.9	7.2	7.3	35.2
Co. D.	6.5	5.1	6.0	5.5	6.2	29.3
Total	63.7	68.3	69.3	71.9	62.0	

TABLE II. COMPARISON OF GRASS YIELDS

Source of Variation	df	F reqd. 5%	F obtained[1]						
			Per. 1	Per. 3	It.	S. r.	Co. N.Z.	Co. D.	Total
Treatments	4	2.87	. –	2.16–	1.37–	1.50–	1.55–	1.94–	1.40–
[2]Lin.	1	4.35	. –	. –	. –	. –	2.44–	2.33–	. –
Curv.	1	4.35	. –	8.04*	4.91*	. –	. –	1.57–	4.69*
Dev.	2	3.49	. –	. –	. –	2.56–	1.73–	1.93–	. –
Residual	20								
Coefficient of Variation (per plant)			17.4	34.4	21.7	21.3	14.9	16.1	

[1]. = F values < 1
– = not significant
(*) = just fails to be significant at 5% level
* = significant at 5% level of probability
** = significant at 1% level of probability
[2]Lin. = linearity of response to initial pH level
Curv. = increments due to curvilinearity
Dev. = deviations from quadratic response

It is seen in Table II that when the relationship between treatments was ignored, none of the grass species showed significantly different yields at the different acidity levels. However, there were significant trends in the response curves for series Per. 3 and It., in both of which there was a significant quadratic

response; that is, an optimum pH for growth could be found, the response curve declining on both sides of this value. The response curve for the totals of all treatments for all grass series was also quadratic, and as a result it can be stated that in the population represented by the plants and species used, the response curve reached a maximum at a certain pH and fell to lower values on either side. This optimum acidity for the grasses as a whole, estimated from the above tests, was pH 5.43 under the conditions of this experiment.

(b) *Clovers*: The yields of herbage from clovers growing at the various acidity levels are recorded in Table III.

TABLE III. AVERAGE YIELD OF CLOVERS PER PLANT
(grams dry matter in 12 months)

Series	TREATMENTS					Total
	N	S	M	V	X	
Red C.	44.5	42.4	50.5	44.5	23.5	205.4
Red M.	84.5	122.0	123.0	89.0	29.3	447.0
Wh. 1	43.8	65.1	87.5	89.2	24.8	310.4
Wh. 2	26.5	31.8	31.4	48.6	21.1	159.4
Total	199.3	261.3	292.4	271.3	98.7	

The very much greater yields of clovers than of grasses (c.f. Table I) lends support to the conclusion that nitrogen deficiency was a major limitation with the latter series of plants. All clovers were nodulated to some extent in all treatments, most of the plants having a large number of normal looking and apparently active

TABLE IV. COMPARISON OF CLOVER YIELDS

Source of Variation	df	F required 5% 1%	F obtained[1]				
			Red. C.	Red M.	Wh. 1	Wh. 2	Total[3]
Treatments	4	2.87 (4.43)	8.01**	27.85**	45.1**	5.51**	5.08 *
[2]Lin.	1	4.35 (8.10)	14.53**	54.59**	3.49 –	. –	4.57(*)
Curv.	1	4.35 (8.10)	14.66**	53.36**	166.0 **	10.77**	14.98**
Dev.	2	3.49 (5.85)	1.43 –	1.73 –	5.42 *	5.55 *	. –
Residual	20						
Coefficient of Variation (per plant)			20.5	18.1	15.1	30.7	

[1], [2] Notation same as for Table II

[3] In this column Residual df = 12, F required = 4.75 (9.33).

nodules. However, in the Treatment X for each series there were only a few nodules to each plant and most of these were large, brown and many branched, so that effective nitrogen fixation could not be expected. The mean clover yields in the various soil treatments are compared graphically in Fig. 1 and the statistical analyses of the plant yields are summarised in Table IV.

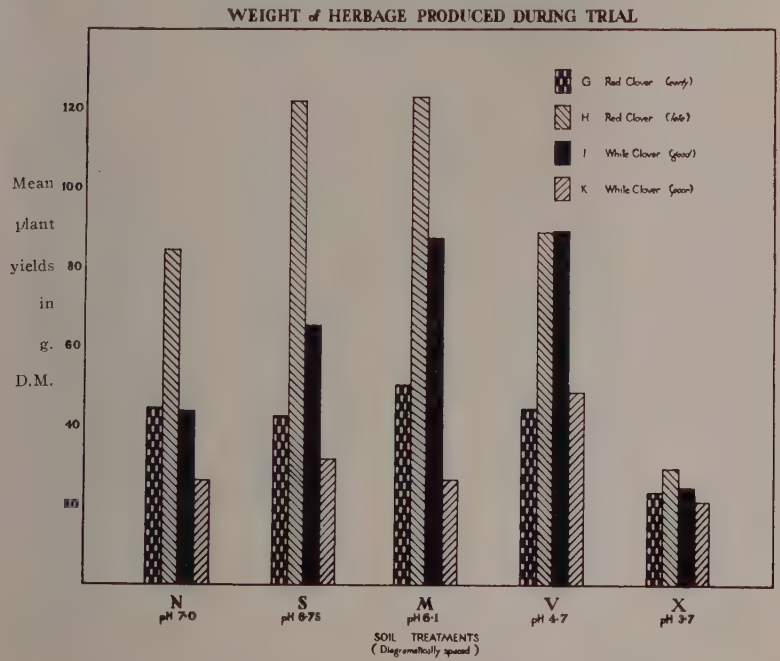


Fig. 1.—Comparison of clover yields at various soil acidities

By an examination of Tables III and IV it is seen that the reactions of the different clovers to the various levels of soil acidity, were as follows:

Series Red C.: In this series, a difference of 11.06 between means was required for significance, so that the only true difference was that the yield of plants in Treatment X was lower than in all other treatments. However, the yields fitted a simple quadratic response curve and the optimum acidity for growth of this species was found to be pH 5.83 (when treatment acidity levels were taken to be those found at the start of the trial).

Series Red M.: In this variety a difference between means of 31.9 was highly significant, so that the highest yielding treatments were S and M. These were followed by N and V which showed no difference but which were much superior to X. The estimated optimum acidity level for this red clover was pH 5.85—almost the

same as that for the previous variety. The difference in total yield of the two red clover varieties did not conform with their field performance, and the low yield of the cowgrass probably was due to a peculiarity of the plant chosen to represent this variety.

Series Wh. 1: Here a difference of 12.23 between means was required for significance at the 5 per cent level. Thus there was definite superiority of yield for Treatments M and V with S next in order, then N and again with X below all others. In this trial the calculated optimum acidity level for this white clover was pH 5.47, and this, with the excellent growth in Treatment V, suggests that liming to stimulate clover growth may not always be necessary.

Series Wh. 2: In this series a difference of 12.91 between means was required for significance, so that Treatment V gave the highest yield and there was no true significance between the other four treatments. The estimated level of acidity optimum for growth of this strain was pH 5.34.

It will be seen in Table IV that in each of the white clover strains there were significant departures from the quadratic regression, indicating that the response curve was more complex than a simple second degree curve.

A test carried out on the treatment totals for the four clover series showed that in the population represented, the response curve reached a definite maximum at a certain level of acidity, and this level under the conditions used was pH 5.65.

B. Root weights of individual species

(a) *Grasses*: At the close of the experiment the plant roots were carefully freed of soil, then oven dried and weighed. As the roots from treatments were weighed in bulk only, the statistical treatment of results is limited. Grass root weights are recorded in Table V.

TABLE V. MEAN WEIGHT OF GRASS ROOTS
(grams dry matter in 12 months)

Series	TREATMENTS					Total
	N	S	M	V	X	
Per. 1	4.6	6.7	7.8	7.7	12.7	39.5
Per. 3	4.8	6.4	4.8	5.2	7.0	28.2
It.	5.4	7.0	5.0	14.8	14.0	46.2
S. r.	8.6	9.6	8.8	9.8	7.4	44.2
Co. N.Z.	5.1	3.3	10.0	7.4	11.0	36.8
Co. D.	4.8	3.4	4.0	4.0	8.6	24.8
	33.3	36.4	40.4	48.9	60.7	

It can be seen that the general trend was for the total weights of the grass roots to increase as the soil became more acid. A regression analysis of treatment totals gave a highly significant value of F of 13.83 for the linearity of this trend, with no significant departures from linearity. This was in contrast with the situation in the case of the grass herbage where there was a significant curved regression. It is possible that the increase in root weight in the acid soils may have been due to the lack of decomposition at the low pH levels, but this does not explain the much finer rootlets found in the most acid soil compared with those in the less acid treatments (see Fig. 2).

Fig. 2.—Root growth of Danish cocksfoot

(b) *Clovers*: Difficulties were experienced in separating white clover roots because of the condition of the soil and the delicate nature of the roots, but it was obvious from the appearance of roots and soil when removed from the pots that the trend was the same as that for the red clovers. Only the red clover roots were weighed and these weights are recorded in Table VI. Representative roots of each treatment are shown in Fig. 3.

TABLE VI. MEAN WEIGHT OF RED CLOVER ROOTS
(grams dry matter in 12 months)

Series	TREATMENTS					Total
	N	S	M	V	X	
Red C.	52.0	38.5	24.6	14.4	12.1	141.6
Red M.	52.4	44.8	26.8	15.6	10.5	150.1
	104.4	83.3	51.4	30.0	22.6	

FIG. 3.—Root growth of red clover, cowgrass

The picture here was the opposite of that found in the case of grass roots for the weights of clover roots decreased very markedly as acidity increased. A regression analysis of treatment totals gave highly significant F values of 520.5 and 45.6 for the linearity and the curvelinearity of the response curves. In this case the

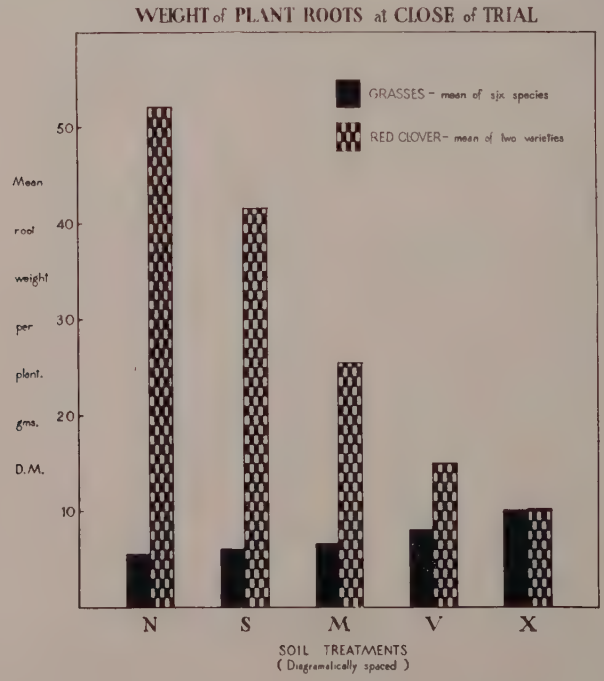


FIG. 4.—Comparison of root weights of grasses and clovers

regression was negative with the degree of acidity whereas with the grasses the regression was positive. This difference is illustrated in Fig. 4.

In view of these results, and particularly of the poor root development of the white clovers in the V treatments despite the good herbage yields in these soils, it was decided to conduct a simple observational trial with a plant species known to prefer acid soils. Rooted cuttings of *Erica Willmoreana* were chosen for this purpose and planted in the bulked soils from the various clover treatments. At the end of three months the results were very well defined. The growth of the tops of the plants was greatest in the V soil, followed in order by Treatments M, S, X and N. However, the root picture was very different, the X and V treatments having very short, stunted roots, brown in colour and almost dead looking, while the roots in the soils of lower acidity were greatly increased in length and the colour was creamy white. Thus, in the case of both the *Erica* and the clovers there was a lack of obvious relationship between top growth and root size. Bates[40] has shown that the roots of white clover did not branch in a layer of acid soil between two less acid soils and also that the root growth was poor if all the soil was acid, but in all cases he found the growth of herbage was similarly reduced.

C. *Induced changes in soil acidity*

The acidities of the soils of each treatment, as measured at the start, the middle, and the end of the trial, are recorded in Table VII.

TABLE VII. ACIDITY OF SOIL TREATMENTS

Treatment	Soil at planting (pH)	After 6 months		After 12 months	
		Grass soil (pH)	Clover soil (pH)	Grass soil (pH)	Clover soil (pH)
N	7.2	7.2	7.0	7.2	6.3
S	6.75	6.8	6.7	6.7	6.0
M	5.95	6.0	6.1	6.5	5.5
V	4.5	4.9	4.7	5.7	4.9
X	3.6	4.0	3.7	4.4	4.4

The results show that there is a marked difference between the pH figures for the grass and clover soils, particularly at the end of the trial, except for Treatment X. Most of this difference is probably due to the greater removal of bases by the actively growing clovers than by the slow growing grasses, but insufficient data was available from this trial to finalise this question.

Because the above variations in acidity were measured in bulked soils only, a further simple trial was conducted to check the results. For this trial twenty-five 8-in. pots of normal station

potting soil were taken, five being left unplanted while the remainder were planted with white clover (10 pots), red clover (5 pots) and Italian ryegrass (5 pots). These were left outside under ordinary weather conditions but additional water was added as required to maintain plant growth, all pots being watered equally to avoid differential leaching. The acidities of the soil in these pots at two different times are shown in Table VIII.

TABLE VIII. ACIDITIES OF SOILS IN SECONDARY TRIAL
(mean pH of replicates)

When tested	Soil treatments			
	Unplanted	Ryegrass	White clover	Red clover
9 mth. after planting	7.44	7.52	7.02	6.97
2½ yr. after planting	7.05	7.15	6.15	6.28

An analysis of the figures for soil acidities gave highly significant F values of 26.1 and 71.4 respectively for the two times of measurement. In both cases there were no significant differences between the two clover planted soils or between the unplanted and grass planted soils, but these groups did differ significantly at the 1 per cent level. This means that the grasses, although growing actively for the first 6–9 months and producing some herbage during all the trial, have not caused the soil pH to differ from that of the unplanted soil, whereas the clovers have brought about a definite decrease in soil pH.

In the literature there appears to be little record of any direct ability of plants to cause changes in the pH of their growing medium apart from observations using water cultures. When water cultures are used for plant growth the buffering of the solutions is often slight and the uptake of nutrients will cause acidity alterations. However, Lundegardh[18], in reporting work by Weiss, does state that a well buffered alkaline solution would not support the growth of maize and oats since the plants were unable to change the acidity, while in a weakly buffered solution the pH was shifted by the plants themselves into the region of their optimum growth. Lundegardh concludes: "many plants appear to have the power of selective absorption or excretion of anions or cations, or some other method, so that they may move the pH of their growing medium towards their optimum".

D. Chemical composition of soils

At the start of the trial the treatment soils were analysed to determine soil bases and acid soluble phosphate, and the results of these tests are recorded in Table IX.

These results show clearly the marked reduction in both "total exchangeable bases" and "acid soluble phosphate" that took place after treatment with the stronger acids in soils V and X.

TABLE IX. TOTAL EXCHANGEABLE BASES AND ACID SOLUBLE PHOSPHATE IN SOILS

Treatment	Total Exchangeable Bases (mg. equiv. %)	Acid Soluble Phosphate (mg. PO_4%)
N	17.35	7.6
S	14.93	8.5
M	12.41	8.1
V	6.96	4.9
X	2.83	2.8

E. Chemical composition of some clover herbage

Herbage from some clover plants at the close of the trial was analysed to see if there was the marked difference in the mineral content of the herbage from the various treatments that would be expected from the soil analyses. The results of these tests are given in Table X.

TABLE X. CHEMICAL ANALYSES OF LAST CUT CLOVER HERBAGE

Clover series	Chemical test	Soil treatments				
		N	S	M	V	X
Red M.	Sol. ash (%)	10.1	9.7	9.6	8.9	9.0
	CaO (%)	1.87	2.12	2.12	1.92	1.92
	P_2O_5 (%)	.65	.65	.64	.62	.59
Wh. 1	Sol. ash (%)	10.1	9.1	9.3	9.1	12.6*
	CaO (%)	1.91	1.84	2.09	2.02	2.51*
	P_2O_5 (%)	.70	.64	.63	.67	.60*
Wh. 2	CaO (%)	1.30	1.41	1.64	1.53	1.89*

*Sample too small for duplicate determination

These results are of particular interest in view of those for "total exchangeable bases" and "acid soluble phosphate" (Table IX) as the percentage of calcium and phosphorus in the herbage did not decrease in proportion to the reduction of bases and available phosphate in the more acid soils. These figures are even harder to explain when they are studied in conjunction with actual herbage yields (Table III).

Thus it is seen that if we could assume the chemical analysis of the clover herbage at the close to hold through all the growth period, then in series Wh. 1 the total weight of calcium removed by the plants in Treatment V was more than twice that removed from Treatment N even though the level of total bases present in the soil V was much less than half that present in soil N. This would indicate that plants, like all living organisms, will make strenuous efforts to maintain a regular internal environment despite a wide range of external environments.

Conclusions

The fact that only a single plant was used to provide plants for all treatments in each series is a disadvantage in this experiment, for although this method did remove one source of variation between plants it also limits the applicability of the results.

From the agricultural point of view, the present results lead to a questioning of the practice of heavy liming for the purpose of stimulating clover growth, for while the added calcium may ultimately be required for stock health and satisfactory soil structure, it has been shown here that clovers will thrive in strongly acid soils.

From the experimental point of view, this trial does pose a number of problems. The first of these concerns the lack of correlation between the growth of roots and tops particularly of the clovers and *Erica* in the various soils. The second is the difference in the way the grass roots and clover roots react to the various levels of acidity. Thirdly, more study is necessary for complete understanding of the difference in soil acidity changes after acidification, and the way these changes may be dependent on the plants growing therein. Finally, some satisfactory method of supplying nitrogen to grasses in pots without altering soil acidity is required before some of the above points can be satisfactorily answered.

Acknowledgments

The author gratefully acknowledges the understanding advice and encouragement of Mr. L. W. Gorman, without whose permission this work could not have been carried out; the assistance of Dr. J. Melville and Mr. R. M. Greenwood who arranged for chemical analyses and acidity testing to be carried out; and the technical assistance of Mr. J. S. Gomez. Thanks are also due to Professor A. W. Hudson, Massey College, for the idea to begin this work, to Mr. C. Fife, Massey College, for guidance in the soil analyses and for carrying out the determination of acid soluble phosphate in the soils, and to Mr. I. D. Dick and Mr. A. C. Glenday of the Applied Mathematics Laboratory for statistical analyses of results.

References

1. Small, J., 1946: "pH and Plants." Baillière, Tindall and Cox, London.

2. Whitney, M.; Cameron, F. K., 1904: Investigations in Soil Fertility. *U.S. D. A. Bur. Soils, Bul. 23.*

3. Oosting, Henry., 1948: "The Study of Plant Communities." p. 179. W. H. Freeman, California.

4. Lyon, T. L.; Buckman, H. O., 1943: "The Nature and Properties of Soil." Macmillan, New York.

5. Hartwell, B. L.; Pember, F. R., 1918: The presence of aluminium as a reason for the difference in the effect of so-called acid soil on barley and rye. *Soil Sci. 6*: 259.

6. Hewitt, E. J., 1947: The resolution of the factors in soil acidity. The relative effects of aluminium and manganese toxicities on farm and market garden crops. *Long Ashton Agric. Hort. Res. Sta. Rep.*

7. Hale, J. B.; Heintze, S. G., 1946: Manganese toxicity affecting crops on acid soils. *Nature, 157*: 554.

8. Morris, H. D., 1948: Soluble manganese as a factor affecting the growth of legumes in culture solutions and in acid soils. *Iowa St. Coll. J. Sci. 23*: 55-6.

9. Hewitt, E. J., 1945: The resolution of the factors in soil acidity. *Long Ashton Agric. Hort. Res. Sta. Rep.* 51-60.

10. Albrecht, W. A.; Schroeder, R. A., 1942: Plant nutrition and the hydrogen ion: I. Plant nutrients used most effectively in the presence of a significant concentration of the hydrogen ion. *Soil Sci. 53*: 313-7.

11. Stewart, A. B., 1950: Fertilisers and lime in Scotland. II. Lime and soil fertility. *Scot. Agric. 30*: 149.

12. Truog, E., 1946: Soil reaction influence on availability of plant nutrients. *Proc. Soil Sci. Soc. Amer. 11*: 305-8.

13. Harmer, P. M.; Benne, E. J., 1946: The effects of several minor elements on crops produced on Michigan organic soil, as measured by deficiency symptoms, yields and composition. *Amer. Fert. 105.* No. 6.

14. Albrecht, W. A., 1941: Drilling limestone for legumes. *Missouri Agric. Exp. Sta., Bull. 429.*

15. Albrecht, W. A., 1943: Soil and livestock. *Land, 2*: 289.

16. Fried, M.; Peech, M., 1946: The comparative effects of lime and gypsum upon plants grown in acid soils. *J. Amer. Soc. Agron., 38*: 614.

17. Koslowska, A., 1934: The influence of plants on the concentration of hydrogen ions in the medium. *J. Ecol. 22*: 396.

18. Lundegardh, H., 1931: "Environment and Plant Development." Arnold, London.

19. Arnon, D. I.; Johnson, C. M., 1942: Influence of hydrogen-ion concentration on the growth of higher plants under controlled conditions. *Plant Physiol. 17*: 525-39.

20. Guest, P. L.; Chapman, H. D., 1945: Some effects of pH on growth of citrus in sand and solution cultures. *Exp. Sta. Rec. 93*: 22.

21. Duggar, B. M., 1920: The effect of conditions on the relation of seed plants to hydrogen-ion concentration in nutrient solutions. *Science, 52*: 416.

22. Tarr, L. W.; Noble, S. E., 1922: The effect of hydrogen-ion concentration upon the growth of certain seedlings. *Del. Agric. Exp. Sta. Bull. 131.*

23. Powers, W. L., 1927: The effect of hydrogen-ion concentration on the growth of certain plants. *Soil Sci. 24*: 1.

24. Pizer, N. H., 1945: Soil analysis and advisory problems, II. *J. Min. Agric. 52*: 205.

25. Salter, R. M.; McIlvane, 1917: The effect of reaction of solution on germination of seeds and on the growth of seedlings. *J. Agric. Res. 19*: 73.

26. Arrhennius, O., 1922: *Arch. Bot. 18*: 1-54.

27. Noer, O. J., 1928: The nature of soil acidity and how it develops. *U.S. Golf Assoc. Bull. 8*: 3.

28. IVANOFF, S. S., 1948: Chlorosis and nodulation of cowpeas as affected by trial sulphur applications to calcareous soil in the green house. *Plant Physiol. 23*: 162.

29. MCILVANE, T. C.; POHLMAN, G. G., 1949: Crop Growth and Soil Reaction. *W. Va. Agric. Exp. Sta. Bull. 337.*

30. OWEN, O., 1943: Effect of sulphur and sulphuric acid on reaction of a tomato soil. *Cheshunt Exp. Res. Sta. Rep.* p 67-8.

31. OVERLEY, F. K.; ALLMENDINGER, D. F., 1948: Effect of sulphur and sulphuric acid applications upon soil pH values and cork spot development of Buerre d'Anjou pears. *Proc. Amer. Soc. Hort. Sci. 51*: 119-22.

32. REID, Mary E., 1932: The effects of soil reaction upon the growth of several types of bent grasses. *U.S. Golf Assoc. Bull. 12*: 196.

33. SMITH, A. M.; ROBERTSON, I. M., 1931: The influence of the plant upon seasonal changes in soil acidity. *J. Agric. Sci. 21*: 822.

34. LUTZ, H. J.; CHANDLER, R. F., 1946: "Forest Soils." Chapman & Hall, London.

35. MCNEUR, A. J. Unpublished data.

36. SCHOLLENBERGER, C. J.; DREIKELKIS, F. R., 1930: Analytical methods in base exchange investigations on soils. *Soil Sci. 30*: 161.

37. BRAY, R. H.; WILLHITE, F. M., 1929: Determination of total replaceable bases in soils. *Industr. Engng. Chem. (Anal. Ed.) 1*: 144.

38. BURD, J. S.; MURPHY, H. F., 1939: The use of chemical data in the prognosis of phosphate deficiency in soils. *J. Ecol. 22*:

39. SCHNEIDER, E. O., 1950: *Pa. State Coll. Agric. Rep. 63*: 45.

40. BATES, G. H., 1934: The relation of leaf size to root structure in *Trifolium repens*. *J. Ecol. 22*: 271.

EFFECTS OF SHEEP DUNG AND URINE ON A SOIL UNDER PASTURE AT LINCOLN, CANTERBURY, WITH PARTICULAR REFERENCE TO POTASSIUM AND NITROGEN EQUILIBRIA

By A. J. Metson and Frances B. Hurst, Soil Bureau, Department of Scientific and Industrial Research, Wellington

(*Received for publication, 12 June 1953*)

Summary

The chemical properties of the top three inches of soil were studied during a four-year experiment, laid down by the Grasslands Division, involving sheep grazing with and without return of dung and urine. The results were:

(1) Pasture brought about a marked differentiation of the chemical properties of the surface inch of soil from the 1–2-in. and 2–3-in. layers.

(2) More exchangeable potassium was found in the "full-return" (F.R.) than in the "no-return" (N.R.) plots.

(3) The removal of up to 1,000 lb. per acre of K_2O in dung and urine did not significantly lower the exchangeable-K level of the soil of the N.R. plots.

(4) No change in the "potassium supplying power" of the soil, as determined by a normal nitric acid method, could be detected on either the F.R. or the N.R. plots.

(5) No depletion of soil nitrogen occurred as a result of the removal of up to 1,200 lb. per acre of nitrogen in dung and urine. The maintenance of the soil nitrogen level was due to clover dominance on the N.R. plots and, presumably, enhanced activity of the associated nitrogen-fixing bacteria.

(6) No appreciable gain in soil nitrogen occurred on the plots which were grazed normally. Presumably, this was due to the lower clover yields and to reduced activity of the symbiotic nitrogen-fixing bacteria, as compared with the N.R. plots.

(7) Loss of calcium from the top 3 in. of soil was proportional to the quantity applied in ground limestone and superphosphate, and was about 56 per cent of the amount added.

(8) Determinations of nitrate nitrogen and ammonia nitrogen were made on four occasions. Nitrate-N was invariably low, usually less than 1 p.p.m., while ammonia-N figures varied from 12 to 112 p.p.m. Differences between F.R. and N.R. plots were of doubtful significance.

(9) If the design of a field experiment is inadequate, or if the area chosen is not sufficiently uniform, much subsequent work may be of limited value. Where soil conditions may have a bearing on the results, soil surveys and relevant soil analyses should be made before the final plan of the experiment is decided upon.

Although the soil analytical data for this experiment are not as complete as would be desirable, they indicate that soil analyses may be very useful in supplementing botanical and chemical studies of the pasture, in the evaluation of the results of field experiments involving the grazing animal.

Introduction

Following a similar experiment at Palmerston North (Sears and Newbold, 1942; Sears, Goodall, and Newbold, 1948) the Grasslands

Division of the Department of Scientific and Industrial Research conducted an experiment at Lincoln (Sears and Thurston, 1953) to measure the effect of lime and superphosphate and of sheep excreta on the yield and botanical composition of the pasture. After the pasture had been sown (with the first topdressing of fertilizer) and before the sheep were put out to graze, the Soil Bureau was invited to examine the influence of the various treatments on the soil. Samples were taken for analysis at this stage of the experiment and again at the conclusion of the grazing period (about 3½ years later). Samples for determination of nitrate and ammonia were taken on four occasions. The work of the Soil Bureau was confined to this collection and analysis of soil samples, together with a soil survey of the experimental area, the object being to see whether soil factors could be related to the results of the pasture studies.

Briefly, the Lincoln Experiment conducted by Sears and Thurston (1953) consisted of grazing a mixed pasture with and without normal return of dung and urine, and with and without the addition of lime and superphosphate. Details of the treatments, with the total amounts of topdressing added over the four years of the experiment, are shown in Figure 1. Plots 13, 14, 15, and 16 were grazed by sheep as in normal farming practice, and in this paper are referred to as "full-return" (F.R.) plots. Plots 9, 10, 11, and 12 were grazed by sheep fitted with harness to prevent the return of dung and urine to the soil, and are referred to as "no-return" (N.R.) plots. It was found that on the N.R. plots the growth was dominated by red clover, especially in the summer and autumn periods; on the F.R. plots the total annual production of herbage was the same (9,600 lb. of dry matter per acre), but the pasture was dominated by ryegrass and other grasses. The pasture on the N.R. (clover-dominant) plots was higher in calcium but lower in potassium than that of the F.R. (grass-dominant) plots. Lime and superphosphate topdressing gave responses on both series of plots, the response being somewhat greater on the N.R. plots. At the conclusion of the four years grazing trial, two successive crops of wheat were grown with a view to showing up any residual fertility differences. This experiment gave a negative result as the wheat yields on both series of plots were the same.

This experiment may be contrasted with the results of the trial at Palmerston North, where total pasture yields were much higher, and where the F.R. treatment gave an annual dry matter yield of 14,000 lb. as against 10,600 lb. for the N.R. group.

Experimental Procedure

Description of Plots

The following description of the plots was supplied by Mr. C. S. Harris, of the Soil Survey Division, Christchurch.

"The plots were laid down by the Grasslands Division of the Department of Scientific and Industrial Research on the property of the Agronomy Division (now Crop Research Division) at Lincoln, in May, 1944. The eight plots were each one tenth of an acre in area and the layout was as shown in Fig. 1.

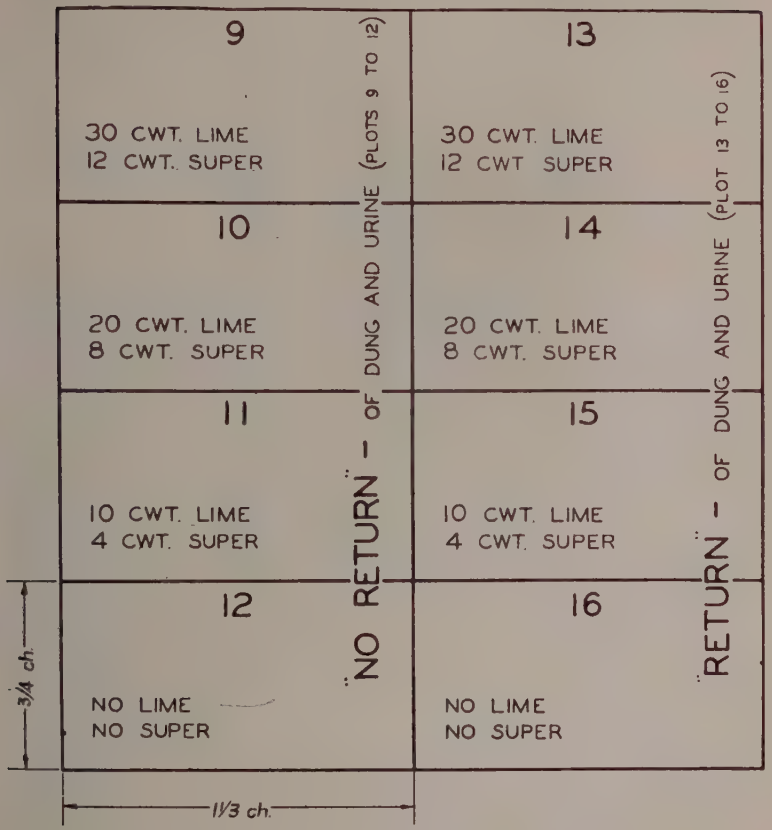


FIG. 1.—Layout of plots.

"A field examination was made by the Soil Survey Division in August of the same year. The soil is classified as *Wakanui* silt loam on sand,* and on the two-mile survey of the Canterbury Plains and Downs is grouped with Wakanui silt loam. On this area the soil has been formed from greywacke alluvium derived from the Southern Alps and deposited by the Waimakariri River in geologically recent times. The soil is intermediate in age and fertility between the older, more leached Lismore soils at Burnham and the younger, less leached and more fertile Waimakariri and Kaiapoi silt loams between Christchurch and the Waimakariri River.

"The plot area was nearly flat with several small very slight depressions a few inches below the general level. Topsoil in these depressions was slightly heavier than over the rest of the area, but over the plots as a whole so little profile variation was found that it would be expected to have no significant effect on the experimental results.

* Shown tentatively as "Springston silt loam on sands" in Proc. N.Z. Grasslands Assoc. 1948. p. 25; and in Guide to Crop Research Station, Department of Scientific and Industrial Research, 1951.

"The profile was:

7½–9 in.	silt loam, dark grey, small crumb structure
9 in.	heavy silt loam, brown yellow to brown grey
15 in.	heavy silt loam, brown yellow to brown grey, slightly mottled rusty loam.
On	sand to loamy sand, brownish grey.

"The soil type is one of the best drained of the Wakanui series, due to the porous sand at the bottom of the profile."

The average annual rainfall at Lincoln is 25.9 in., and the mean annual temperature 51.1°F. The climatic type, according to Thornthwaite (1948) is $C_2B_1'a'd$, and there is a water deficiency in an average year from January to March.

Sampling and Analysis

Samples for the main chemical analyses were taken at 0–1, 1–2, and 2–3-in. depths. For each sample, 85 small cores were taken on a grid system; preliminary analyses indicated that this number of cores would practically eliminate sampling errors. Samples below three inches were not taken because it was thought that in a short period under pasture the changes below this depth would be small. This was unfortunate, in view of the calculations made subsequently, but it should not invalidate the main conclusions. Samples for determination of *nitrate nitrogen* and *ammonia nitrogen* were taken on four occasions, results from three only being reported. Samples were taken from Plots 9, 12, 13, and 16 only; 0–1 and 1–3-in. depths were sampled, each sample consisting of 85 cores. Samples from the first and second of these sets were extracted at Lincoln approximately two hours after sampling, and the toluene-treated extracts were analysed for nitrate and ammonia on the following day. Soil samples from the third set were bottled and treated with toluene at Lincoln, and extracted and analysed the following day in Wellington. Davies *et al.* (1940) found three drops of toluene to 500 g. of soil satisfactory for stabilising soil nitrate values for several days. In the present work, nitrates were invariably very low whether samples were treated or not, so that no conclusion could be reached concerning the efficacy of toluene as a nitrification inhibitor. From the few tests made on untreated samples and on samples treated with different amounts of toluene and kept for varying lengths of time, it appeared, however, that ammonia nitrogen values could not be stabilised in this way.

The methods of chemical analysis used were mainly those normally used by the Soil Bureau for the examination of the type soil samples for soil survey purposes and for other general work, and were essentially as described by Metson (1953).

Potassium-supplying power was estimated by the N nitric acid extraction procedure (Wood and De Turk, 1941; Rouse and Bertramson, 1950; Reitemeier, Brown and Holmes, 1951; Pratt, 1952). In the present work, instead of making a single extraction with boiling N nitric acid, as used by the workers mentioned, four successive extractions with 50-ml. portions of boiling N HNO_3 were made, using a

4-g. sample of soil. It was hoped by this modification to obtain a better idea of the potassium-supplying power of the soil than would be given by a single extraction (which in any case is subject to a slight uncertainty as it must be corrected for exchangeable K, either by subtraction from the nitric acid figure or by removal of exchangeable K by an ammonium acetate leaching before applying the nitric acid procedure).

RESULTS AND DISCUSSION

Since one application of fertilizer had been made before the plots were sampled, the initial chemical status of two plots only—Nos. 12 and 16, which received no fertilizer—is known in detail, although it may reasonably be assumed that the 1944 analyses for all plots were close to the initial values, except for those properties which would be directly affected by lime and superphosphate applications, e.g., citric-soluble P_2O_5, Total Exchangeable Bases, Percentage Base Saturation, Exchangeable Ca. That this assumption is justified is shown by the analytical values for the remaining plots; these values (not reported) except for those properties affected by the fertilizer application, were in very good agreement with those for plots 12 and 16 (Table I), showing that the chemical uniformity of the topsoil of the area was adequate for the purposes of the experiment. Phosphate values are not reported, as consistent results by the citric acid method were not obtained, the figures increasing after several months storage in the air-dry condition.

For the reasons mentioned, exact analytical data are lacking for the initial status of most of the plots; results for several plots have therefore been averaged wherever possible so that the broad trends would become more evident. Furthermore, because of the marked differentiation of the top inch of soil from the 1–2-in. and 2–3-in. depths, the effects of the treatments are seen most clearly when the analyses for the three depths are averaged. Accordingly, these averaged figures have been included in the tables (Tables II and III). This marked increase in plant nutrient elements of the top inch of soil under grass was observed even more strikingly on experimental turf plots at Hokowhitu (Metson and Gibbs, 1946 (Table II)), which, however, had been dail down for nine years as compared with less than four in this experiment.

At this point it may be mentioned that the original exchangeable potassium level of this soil, as shown by the 1944 analyses (Table II), is rather low in comparison with most New Zealand topsoil values, and perhaps even within the range of a possible potash response. It has long been realized, of course, that exchangeable K figures are not a good guide to the potassium status of the soil as shown by field responses. Potassium might be expected to be deficient at values below 0.3 m.e.%, and adequate above, say, 0.6 m.e.%, but exchangeable K values generally do not seem to be at all informative. The original Lincoln plot values, therefore, did not at first sight appear to call for comment.

TABLE I. ANALYSES INDICATING VARIATION IN SOIL PROPERTIES WITHIN PLOTS 9 AND 13

Plot No. and Treatment	Property Determined	Variations in analyses between small areas of a single plot. (Sample taken 4 months after commencement of grazing: Sampling date, January 1945)				Analyses for whole plots before grazing commenced† (Sampling date September 1944)	Analyses for whole plots at end of grazing period.† Sampling date February 1948)
		Highest value *	Lowest value *	Mean of 6 values *	Mean Analyses for whole plot **		
Plot 9		(1)	(2)	(3)	(4)	(5)	(6)
High Fertilizer and No Return of Dung and Urine.	pH	6.3	6.1	6.2	6.1	5.9	6.1
	C	3.3	2.5	2.8	2.8	2.8	4.2
	N	0.24	0.21	0.22	0.22	0.23	0.31
	Cation Exchange Capacity	15.3	13.7	14.5	14.8	14.2	16.9
	Total Exchangeable Bases	9.2	7.5	8.5	8.2	8.4	13.4
	Percentage Base Saturation	63	51	59	56	59	79
Depth: 0-1 in.	Exchangeable Ca	8.7	7.2	8.0	7.7	7.1	11.5
	Exchangeable Mg	1.2	0.9	1.0	1.0	0.8	1.4
	Exchangeable K	0.60	0.45	0.55	0.60	0.45	0.70
Plot 13	pH	6.3	6.0	6.2		5.8	6.3
High Fertilizer and Full Return of Dung and Urine.	C	3.2	2.6	2.9		2.9	4.0
	N	0.28	0.24	0.25		0.23	0.31
	Cation Exchange Capacity	15.9	14.1	14.9		14.1	17.4
	Total Exchangeable Bases	10.6	8.1	9.2		8.4	14.3
	Percentage Base Saturation	69	55	62		60	82
Depth: 0-1 in.	Exchangeable Ca	8.6	6.7	7.7		7.3	11.5
	Exchangeable Mg	1.6	1.1	1.3		1.1	1.8
	Exchangeable K	1.20	0.65	0.90		0.55	1.70

* Six samples, each of 60 cores from an area of 1 sq. ft., were taken from each of plots 9 and 13 and analysed separately.

** Mean of four analyses, each of a sample consisting of 60 random cores from the whole plot.

† Samples consisted of 85 cores from the whole plot, taken on a grid system.

TABLE II. CHEMICAL PROPERTIES OF LINCOLN DUNG AND URINE EXPERIMENTAL PLOTS—SEPTEMBER, 1944.

Lab. No.	Depth (in.)	pH	Organic C (%)	Total N (%)	CATION EXCHANGE						Plot No.	Treatment
					Exchange capacity (m.e.%)	Total Bases (m.e.%)	Base Satn. (%)	Ca (m.e.%)	Mg (m.e.%)	K (m.e.%)		
3398A	0–1	5.3	2.8	0.22	14.1	5.5	39	4.4	1.0	0.45	12	No grazing and no fertilizers.
3398B	1–2	5.2	2.8	0.23	14.4	5.2	36	4.6	0.9	0.40		
3398C	2–3	5.4	2.8	0.23	14.3	5.2	36	4.7	0.9	0.40		
3398A-C (Average)	0–3	5.3	2.8	0.23	14.3	5.3	37	4.6	0.9	0.40		
3402A	0–1	5.4	2.8	0.23	14.0	6.0	43	4.8	0.8	0.45	16	No grazing and no fertilizers.
3402B	1–2	5.4	2.9	0.22	13.6	5.8	43	5.0	0.8	0.40		
3402C	2–3	5.4	2.8	0.23	13.5	6.0	44	5.3	0.8	0.40		
3402A-C (Average)	0–3	5.4	2.8	0.23	13.7	5.9	43	5.0	0.8	0.40		

TABLE III. CHEMICAL PROPERTIES OF LINCOLN DUNG AND URINE EXPERIMENTAL PLOTS—FEBRUARY, 1948.

Lab. No.	Depth (in.)	pH	1% Citric soluble P_2O_5 (%)	Organic C (%)	Total N (%)	CATION EXCHANGE						Plot No.	TREATMENT	
						Exchange capacity (m.e.%)	Total Bases (m.e.%)	Base Satn. (%)	Ca (m.e.%)	Mg (m.e.%)	K (m.e.%)		Animal Manures	"Artificial" Fertilizers
4834A	0–1	6.1	0.047	4.2	0.31	16.9	13.4	79	11.5	1.4	0.70	9	N.R.	12 cwt./ac. superphosphate 30 cwt./ac. lime
4834B	1–2	5.9	0.037	3.4	0.24	15.4	10.2	66	9.0	0.9	0.35			
4834C	2–3	5.7	0.033	2.9	0.23	14.9	8.6	58	7.3	0.8	0.35			
4834A-C (Average)	0–3	5.9	0.039	3.5	0.26	15.7	10.7	68	9.3	1.0	0.45			
4837A	0–1	5.3	0.029	3.4	0.25	15.8	7.3	46	5.3	1.2	0.50	12	N.R.	None
4737B	1–2	5.3	0.026	3.1	0.22	14.6	5.9	40	4.9	0.8	0.30			
4837C	2–3	5.4	0.025	2.8	0.22	14.1	6.0	43	5.0	0.8	0.30			
4837A-C (Average)	0–3	5.3	0.027	3.1	0.23	14.8	6.4	43	5.1	0.9	0.35			
4838A	0–1	6.3	0.060	4.0	0.31	17.4	14.3	82	11.5	1.8	1.70	13	F.R.	12 cwt./ac. superphosphate 30 cwt./ac. lime
4838B	1-2	5.8	0.042	3.4	0.26	15.5	10.5	68	8.9	1.2	0.85			
4838C	2–3	5.7	0.035	3.0	0.22	14.6	9.2	63	7.6	1.1	0.75			
4838A-C (Average)	0–3	5.9	0.046	3.1	0.26	15.8	11.3	71	9.3	1.4	1.10			
4841A	0–1	5.6	0.038	3.6	0.28	15.6	8.6	55	5.8	1.6	1.30	16	F.R.	None
4841B	1–2	5.2	0.030	3.1	0.23	14.2	6.2	44	4.8	1.0	0.55			
4841C	2–3	5.3	0.023	2.9	0.22	14.4	6.2	43	5.1	0.9	0.40			
4841A-C (Average)	0–3	5.4	0.032	3.2	0.24	14.7	7.0	47	5.2	1.2	0.75			

Effect of Animal Manures

The plant nutrient elements returned by sheep dung and urine have been measured in detail, and their effect on the yield and composition of the pasture has been closely examined (Sears and Newbold, 1942; Sears, Goodall, and Newbold, 1948; Sears and Thurston, 1953). Sears (1949), and Sears and Thurston, have emphasized the very high quantities of the plant food elements N, P, and K returned to the sward by grazing animals on high-producing pastures.

Doak (1949, 1952) has discussed the fate of the nitrogenous constituents, while Thompson and Coup (1940b, 1943) have measured the effect of concentrated applications of stock urine on the ammonia and nitrate content of the soil. The principal plant nutrients returned in animal excreta are calcium and phosphorus (almost entirely in dung) and nitrogen and potassium (mainly in the urine).

It might be expected that, in the present experiment, changes in the plant food elements of the soil due to dung and urine would show up mainly in organic matter and in potassium, since applications of fertilizers would tend to mask possible changes in calcium and phosphorus levels. Table IV summarizes the effects of sheep dung and urine on the chemical properties of the soil.

It is of interest to note that there is no evidence for the animal excreta having increased the organic matter in the soil, even in the top in (see figures for C and N, Table IV). Small, but probably significant increases have occurred in pH, citric-soluble phosphate, base saturation, and exchangeable magnesium; but the most striking difference has occurred in exchangeable potassium. This has risen to a high level in the top inch and increases are perceptible even at the 2–3-in. depth. Increases in pH would be expected as a result of the hydrolysis of urea nitrogen to ammonia, although the effect is transitory (Doak, 1952).

The chemical changes which can be attributed to grazing, or more strictly the return of sheep dung and urine, are therefore rather small and evident mainly in the top inch of soil. This result is not altogether surprising, as the net effect of grazing is not to add plant nutrients to the soil, but simply to return in the form of dung and urine most of the nutrient elements taken up from the soil through the pasture consumed; no plant food elements are actually added to the soil through the agency of the grazing animal. More surprising, however, is the converse effect—that due to the non-return of the dung and urine. In terms of plant foods, this removal of animal excreta represents a considerable drain on the fertility reserves of the soil, as shown by the data of Sears and Thurston (1953), and yet the effect on the fertility level of the soil, as shown by chemical analysis, has been negligible. This unexpected result is discussed in the sections on potassium and nitrogen.

Effect of "Artificial" Fertilizers

Table V shows the effect of lime and superphosphate on the soil. Total nitrogen and cation exchange capacity figures show

TABLE IV. EFFECT OF SHEEP DUNG AND URINE ON THE TOPSOIL—ANALYSES OF SAMPLES TAKEN FEBRUARY, 1948 (AVERAGED)

Depth (in.)	pH	1% Citric soluble P_2O_5 (%)	Organic C (%)	Total N (%)	CATION EXCHANGE					Plot Nos.	Common Treatment
					Exchange capacity (m.e.%)	Base Satn. (%)	Ca (m.e.%)	Mg (m.e.%)	K (m.e.%)		
0–1	5.75	0.040	3.9	0.30	16.6	63	8.7	1.3	0.60	9–12 (Averaged)	N.R.
0–3	5.6	0.034	3.3	0.25	15.4	55	7.2	1.0	0.40		
0–1	6.0	0.049	3.9	0.29	16.5	68	8.6	1.7	1.40	13–16 (Averaged)	F.R.
0–3	5.65	0.039	3.4	0.25	15.4	58	7.1	1.6	0.85		

TABLE V. EFFECT OF "ARTIFICIAL" FERTILIZERS ON THE TOPSOIL—ANALYSES OF SAMPLES TAKEN FEBRUARY, 1948 (AVERAGED)

Depth (in.)	pH	1% Citric soluble P_2O_5 (%)	Organic C (%)	Total N (%)	CATION EXCHANGE						Plot Nos.	Common Treatment ("artificial" fertilizers)
					Exchange capacity (m.e.%)	Total Bases (m.e.%)	Base Satn. (%)	Ca (m.e.%)	Mg (m.e.%)	K (m.e.%)		
0–1	6.2	0.054	4.1	0.31	17.2	13.9	81	11.5	1.6	1.20	9, 13 (Averaged)	12 cwt./ac. superphosphate 30 cwt./ac. lime
0–3	5.9	0.043	3.5	0.26	15.8	12.0	76	9.3	1.2	0.80		
0–1	5.45	0.034	3.5	0.27	15.7	8.0	51	5.7	1.4	0.90	12, 16 (Averaged)	None
0–3	5.3	0.030	3.15	0.23	14.8	6.7	45	5.2	1.1	0.55		

that there is slightly more organic matter in the highly topdressed soils, probably due to a more luxuriant pasture. Table III indicates a phosphate concentration in the top two inches of soil, while the third inch is very little higher than in the unfertilized plots. The large additions of calcium have raised the exchangeable calcium, base saturation, and pH. Over these four years, there is no evidence for calcium displacing magnesium and potassium from the exchange complex as was found by Dixon and Taylor (1942) after continuous topdressing of Waikato soils.

Lime Losses

Calcium added to the soil in lime and superphosphate may enter the cation exchange complex; it may be taken up by the pasture; it may remain in the soil as calcium carbonate, sulphate, or phosphate; or it may be removed from the upper horizons of the soil by percolating rainwater. It is of some importance to estimate the rate at which lime is lost from the topsoil in order that topdressing can be efficient and economical. This was done by comparing fertilized plots with control plots, using the 1948 analyses. Data used and assumptions made in order to carry out the necessary calculations were, briefly:

(1) *Lime added*

Waikari limestone, of medium fineness, for which no analysis is available, was used. An average of limestone analyses from the Waikari district (Morgan, 1919, pp. 221–2) is 73 per cent $CaCO_3$, and this figure was used for the calculations.

Calcium added in superphosphate was allowed for as 0.54 cwt. $CaCO_3$ equivalent per cwt of superphosphate.

(2) *Lime used*

(a) *Soil*: The lime required to account for the differences in exchangeable calcium of the various plots was calculated from cation exchange analyses, assuming a 3-in. acre to weigh 0.70×10^6 lb. (Doak, 1941).

(b) *Herbage*: On the N.R. plots, since all the herbage was consumed by the sheep and no dung and urine was returned, all the calcium in the herbage was lost. The amounts could be closely estimated from yield and analytical data of the Grasslands Division. For the FR plots the correction for herbage was negligible since it is estimated that grown sheep return about 96 per cent of the ash in herbage to the soil (Sears *et al.*, 1948; Sears, 1949).

(c) *Free $CaCO_3$ and Soluble Salts*: These were negligible.

The results are summarized in Table VI. Annual losses range from 1.9 cwt./acre $CaCO_3$ at the lowest rate of application to 4.1 cwt./acre at the highest. The average figures show that the proportion of lime lost to lime added is fairly constant, and about 56 per cent. Had the lime been 93 per cent pure, the loss would have amounted to about 62 per cent of the lime added. The proportion of lime lost appears to have been slightly greater in the F.R. than in the N.R. plots.

TABLE VI. ESTIMATE OF LOSS OF LIME (AS $CaCO_3$) FROM TOP 3 IN. OF SOIL—CALCULATED FROM ANALYSES OF SOIL SAMPLES TAKEN FEBRUARY, 1948, AND FROM DATA ON HERBAGE YIELDS AND COMPOSITION

$CaCO_3$ required for soil (average) (cwt./ac.)	$CaCO_3$ required for herbage† (average) (cwt./ac.)	Total $CaCO_3$ required (average) (cwt./ac.)	$CaCO_3$ added* (cwt./ac.)	$CaCO_3$ lost from top 3 in.§ (average) (cwt./ac.)	Proportion of added $CaCO_3$ lost (%)	Annual $CaCO_3$ loss (cwt./ac.)	Plots compared	Common Treatment
4.07	0.44	4.5	9.5	5.0	53 } 56	1.9	9 & 10; 10 & 11; 11 & 12	N.R.
3.92	0.02	3.9	9.5	5.5	58 }		13 & 14; 14 & 15; 15 & 16	F.R.
7.63	0.65	8.3	18.9	10.6	56 } 58	2.9	9 & 11; 10 & 12	N.R.
7.48	0.03	7.5	18.9	11.4	60 }		13 & 15; 14 & 16	F.R.
12.30	1.33	13.6	28.4	14.8	52 } 55	4.1	9 & 12	N.R.
11.95	0.04	12.0	28.4	16.4	58 }		13 & 16	F.R.

* Includes Ca added in superphosphate.

† From data of Sears and Thurston (1953).

§ In 46 months since the first application of lime.

The figures for annual lime loss below the 3-in. depth ,TableVI) may be compared with Doak's (1941) estimate of an annual topdressing of 500 to 600 lb. $CaCO_3$ for maintenance of a satisfactory base status at Marton. His figures were derived from plots receiving superphosphate only, as against ones receiving superphosphate plus two tons of lime. His higher figure for annual lime loss may be due to the wetter climate, and the heavier topdressings.

A similar approximate proportionality between the quantity of lime (calcium carbonate) added and that lost from the surface soil has been found by Walker (1952), who gives figures obtained from soil and crop yield data for the loss of lime over three 5-year periods after applying different dressings. His figures for approximate loss of $CaCO_3$ from the surface soil (cwt./acre/year) are:

	100 cwt. dressing	50 cwt. dressing	25 cwt. dressing
1st 5 years	8	5	3
2nd 5 years	4	2½	1½
3rd 5 years	2	1	½

Over the first five years the respective losses amount to 40, 25, and 15 cwt. respectively; or 40, 50, and 60 per cent of the quantity initially applied. Since only 30 cwt. was applied (in several dressings) as the highest treatment in the present work, the figures for the 25-cwt. dressing should be those most nearly comparable. When it is considered that the conditions were so different and that in the present work only the 0–3-in. layer of soil is included, the figure of 60 per cent loss for a 5-year period is not greatly at variance with the 55 per cent loss found for a 46-month period in the Lincoln experiment (Table VI). It is apparent that to obtain any desired degree of pH, or base saturation, lime must usually be added in excess of what is theoretically required to achieve this result. Davies (1938), for example, states that in transferring lime-requirement figures as determined in the laboratory to field conditions a factor of from 1 to 3 is required, depending on the type of soil. Dr. J. K. Dixon, of the Soil Bureau (unpublished work), in liming studies on Southland soils, also found a close relation between lime added and lime lost, and concluded that this loss was the price to be paid in achieving the lime level desired. In this experiment, since lime and superphosphate were both applied to all the fertilized plots, it is impossible to assess the effect of lime alone on the increased pasture yields obtained. Moreover, since the highest pH measured on these plots was only 5.9 (for the 0–3-in. average on Plots 9 and 13 which received the highest rate of fertilizer treatment), it is by no means certain that the optimum rate of liming was attained. Somewhat higher pH values would be expected, for instance, to increase the rate of nitrification, a point discussed below.

Loss or turnover of plant nutrients as affected by the treatments

Sears and Thurston (1953) have calculated the average annual losses of the plant food elements Ca, N, P, and K from the soil of the N.R. plots, and the corresponding turnover of these elements in the F.R. group (in the latter it is assumed that the plant nutrients in the herbage are quantitatively returned to the soil in the dung and urine). Their calculated figures for nitrogen and potassium are as set out in Table VII.

TABLE VII. LOSS OR TURNOVER OF NITROGEN AND POTASSIUM

(Sears and Thurston, 1953)

Treatment	Plot No.	Loss or Turnover of N. (as sulphate of ammonia)	Loss or Turnover of K. (as 30% potash salts)
		cwt./ac./yr.	cwt./ac./yr.
No return No fertilizer	12	11.6	6.2
No return High fertilizer	9	14.8	8.5
Full return No fertilizer	16	12.2	8.6
Full return High fertilizer	13	13.7	10.9

Potassium

Results of the Lincoln Experiment.—From the above results it is seen that on Plot 12 (which received no fertilizers and no dung and urine) potassium equivalent to 6.2 cwt./acre/year of 30 per cent potash salts has been removed, or in 3½ years approximately 730 lb. of K_2O. For Plot 9 the corresponding figure is 1,000 lb. of K_2O. A summary of the data for Plots 9, 12, 13, and 16 is given in Table VIII.

It is seen that exchangeable potassium has not fallen appreciably on the N.R. Plots 9 and 12, the slight drop in the 0–3-in. average value for Plot 12 being of doubtful significance. The figures for the top inch of soil appear to have increased at the expense of the 1–2 and 2–3-in. depths, but this may be regarded as normal under pasture, due to the "organic cycle" effect; it is most apparent on Plot 9 where the yield was higher due to the addition of lime and superphosphate. The F.R. plots show a distinct gain in exchangeable K, again most noticeable in the top inch of soil, and particularly in Plot 13 where the pasture yield was higher. This gain represents merely a transfer of a relatively small (in terms of the total turnover) part of the soil potassium from the non-exchangeable to the exchangeable form.

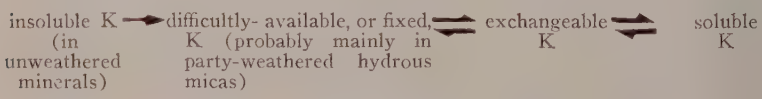
Taking the figure of 0.7×10^6 lb. for a 3-in. acre, the total losses of potassium from Plots 12 and 9 are equivalent to 2.2 and 3.0 m.e.% respectively. On the basis of a 6-in. acre of 2.0×10^6 lb. (actual volume weights for these plots were not determined), these losses are equivalent to 0.78 and 1.06 m.e.% respectively—figures which are still very high compared with the exchangeable K levels. It would appear, therefore, that this soil has an exceptional capacity to supply potassium in available form—a capacity which would not be anticipated from the exchangeable K figures. The problem of the potassium-supplying power of soils has received much attention from soil chemists, and it is of interest to consider some recent views on potassium availability in relation to the present work.

TABLE VIII. POTASSIUM STATUS OF TOP 3 IN. OF SOIL- EXCHANGEABLE POTASSIUM

Depth (in.)	Exchangeable Soil Potassium				Potash removed in dung & urine in 3½ yr.*	Total potash supplied by plot to account for level of soil Exchangeable K			Plot No.	Treatment
	1944	1948	Gain or Loss 0–3-in. average	Gain or Loss 0–3-in. average						
	(m.e.%)	(m.e.%)	(m.e.%)	K_2O (lb./ac.)	K_2O (lb./ac.)	K_2O (lb./ac.)	Exch. K equivalent (m.e.%)	K_2O (lb./ac./yr.)		
0–1	0.45	0.70								
1–2	0.45 } 0.45	0.35 } 0.45	0.00	0	1000	1000	3.0	286	9	N.R. High fertilizer
2–3	0.50	0.35								
0–1	0.45	0.50								
1–2	0.40 } 0.40	0.30 } 0.35	—0.05	—16	732	716	2.2	205	12	N.R. No fertilizer
2–3	0.40	0.30								
0–1	0.55	1.70								
1–2	0.55 } 0.55	0.85 } 1.10	+0.55	+181	0	181	0.55	52	13	F.R. High fertilizer
2–3	0.60	0.75								
0–1	0.45	0.30								
1–2	0.40 } 0.40	0.55 } 0.75	+0.35	+115	0	115	0.35	33	16	F.R. No fertilizer
2–3	0.40	0.40								

* From data of Sears and Thurston (1953).

The potassium-supplying power of soils, and its estimation: The literature on soil potassium has been comprehensively reviewed by Reitemeier (1951). Potassium is one of the abundant elements of soils, occurring in a number of primary silicate minerals, of which muscovite, biotite, orthoclase, and microcline are common soil constituents, and in the secondary minerals of the hydrous mica (illite) group. Total K_2O figures for soils range from a trace to about 6 per cent, with an average value of perhaps 2 per cent. At any one time only a small fraction of the total potassium is in the soluble and exchangeable forms, an amount quite insufficient to supply plant needs for more than a very few seasons on most soils. Moreover, the K-bearing primary minerals are not usually regarded as releasing sufficient potassium by weathering to supply normal crop requirements, except perhaps in a few special cases. To account for the continued availability of potassium—as shown by a lack of response to potash in the field, or by the results of continuous cropping experiments—as well as for the phenomenon of potash fixation, it has therefore been postulated that, on some soils at least, an equilibrium exists between the different fractions of the soil potassium. This has been variously formulated (Wood and De Turk, 1941; Attoe and Truog, 1946), but may be expressed as:


insoluble K (in unweathered minerals)
difficultly- available, or fixed, K (probably mainly in party-weathered hydrous micas)
exchangeable K
soluble K

The fraction of especial interest is the "difficultly-available" or "fixed" K, which is considered to release K into the exchangeable form as the latter is utilized by plants. This difficultly-available fraction is in turn probably regulated by the content of K-bearing minerals, both primary and secondary, in the soil, their rate of weathering, and the extent to which the soil is being leached. The evidence suggests (e.g., Bray, 1937; Bray DeTurk, 1939; Hoover *et al.*, 1949; Rouse and Bertramson, 1950; Reitemeier *et al.*, 1951) that the hydrous micas and other 2:1 type minerals are chiefly responsible for the continued release of potassium by certain soils, although it seems difficult to obtain a clear explanation of the reactions involved. It has been abundantly shown, however, that the reverse reaction—"potassium fixation"—usually occurs when soluble K salts are added to the soil. Bray and DeTurk (1939) have suggested that some mineral, transitional towards a hydrous mica, is formed, which renders added soluble potassium at least temporarily non-exchangeable, thus preventing the establishment of a high equilibrium level of exchangeable soil potassium.

In general, it appears that the exchangeable K level of a soil (which, due to its previous history, may not be an equilibrium level) is not a good indication of its potassium-supplying power; but there is some evidence that the final level of exchangeable K after continuous cropping does correlate well with this property, as measured by total uptake of potassium in excess of the decrease in exchangeable K. The K level reached in this way is presumably

TABLE IX. POTASSIUM STATUS OF TOP 3 IN. OF SOIL—POTASSIUM-SUPPLYING POWER AND TOTAL POTASSIUM*

Potassium-supplying power, as estimated by 4 successive extractions with boiling, normal HNO_3 (includes exchangeable K as shown in adjacent columns)			Exchangeable K		Total K		Plot No.	Treatment
Extraction No.	1944 (m.e.%)	1948 (m.e.%)	1944 (m.e.%)	1948 (m.e.%)	1944 (%)	1948 (%)		
1	2.00 (1.55)†	1.80 (1.35)†	0.45	0.45	2.75	2.65	9	N.R. High fertilizer
2	1.00	0.90						
3	0.85	0.85						
4	0.80	0.85						
Sum	4.65 (4.20)†	4.40 (3.95)†						
1	1.70 (1.30)	1.70 (1.35)	0.40	0.35	2.65	2.60	12	N.R. No fertilizer
2	0.90	0.80						
3	0.80	0.80						
4	0.80	0.80						
Sum	4.20 (3.80)	4.10 (3.75)						
1	2.20 (1.65)	2.40 (1.30)	0.55	1.10	2.70	2.60	13	F.R. High fertilizer
2	0.90	0.85						
3	0.85	0.80						
4	0.75	0.75						
Sum	4.70 (4.15)	4.80 (3.70)						
1	1.60 (1.20)	1.70 (0.95)	0.40	0.75	2.65	2.70	16	F.R. No fertilizer
2	0.80	0.85						
3	0.85	0.75						
4	0.75	0.75						
Sum	4.00 (3.60)	4.05 (3.40)						

* Analyses by R. H. Arbuckle.
† Figures in brackets have exchangeable K deducted.

a measure of the rate of release of K from the non-exchangeable to the exchangeable form (Breland *et al.*, 1950; Evans and Simon, 1950).

Because of the difficulties inherent in lengthy experiments with plants, many attempts have been made to devise chemical methods which would correlate with the results of continuous cropping experiments: of these, long-term electrodialysis (Reitemeier *et al.*, 1951), and extractions with 0.5N HCl (Attoe and Truog, 1946; Evans and Simon, 1950) or boiling N HNO_3 (Wood and De Turk, 1941; Rouse and Bertramson, 1950; Reitemeier *et al.*, 1951; Pratt, 1952) have shown fairly good correlations and have therefore been suggested for assessing the "potassium-supplying power" of soils.

Estimation of the potassium-supplying power of the soil of the Lincoln plots. (Wakanui silt loam, on sand): In the present work the method of extraction with boiling N HNO_3 was used, modified as described above. It should be mentioned that these analyses were made late in 1952, whereas the two sets of samples were taken in 1944 and 1948 respectively. In the intervening period the samples were stored in the air-dry condition; it is possible, therefore, that changes in the forms of the soil potassium may have occurred during this storage period. Exchangeable K figures were determined, along with other data reported in Tables II and III, soon after sampling.

The results of the potassium analyses are given in Table IX. Allowing for analytical and other experimental errors, no differences between the nitric acid-soluble K of the 1944 and 1948 samples can be seen. There appear to be some slight differences between plots, particularly in the first HNO_3 extraction, which (presumably) includes the exchangeable K. Again, there is nothing to suggest that the potassium-supplying power of the N.R. plots has been in any way affected by the removal of potassium equivalent to between 2 and 3 m.e.% for the top 3 in. of soil.

The observation of Sears and Thurston (1953) that "the high potash figures shown by the analyses [of the herbage] are undoubtedly a reflection of the general high level in the soil used for the experiment," is thus substantiated by the soil analyses by the nitric acid method, although the original level of exchangeable K certainly does not suggest it. This soil, therefore, provides an excellent example of the misleading nature of the exchangeable K figure as an indicator of potassium-supplying power, and at the same time points to the promise of the nitric acid method for discriminating more accurately between soils on the basis of their relative potassium status.

As would be expected the loss of K_2O from the N.R. plots is not shown by the total K_2O analyses; the expected loss, if derived entirely from the 0–3-in. depth, would be about 0.1 per cent, which is no greater than the probable analytical error. The K_2O content of the soil is fairly high, at about 2.7 per cent, but even so, about 1/20 to 1/25 of the total has been removed in the N.R. plots without a perceptible falling-off in either exchangeable or N nitric-acid-soluble K. It would appear that this

soil has a high proportion of its total K in a potentially available form.

The plots with return of dung and urine (Nos. 13 and 16) show appreciable increases in exchangeable K, particularly in the top inch of soil, and more especially in the plot receiving high lime and superphosphate (No. 13). These increases do not represent potassium added to the soil, but simply a redistribution of the soil K as a result of grazing. It appears that potassium has been drawn from non-exchangeable forms to maintain the pasture growth, and when it has been returned to the soil in the sheep excreta, it is at least partly in a readily-available form. The result is that a rather high level of exchangeable K is maintained for these "full return" plots—higher than would be expected under cropping, for example. Despite this, there is no evidence of a higher level of nitric-acid-soluble K in the 1948 samples than in the 1944 ones.

The clay content (fraction $< 2\ \mu$) of this soil was about 13 per cent, while the K_2O content of the clay was 5.2 per cent. The clay and silt (2–20 μ) fractions were examined by the X-ray method by Mr. M. Fieldes of the Physical Chemistry Section, Soil Bureau, who reports: "The $< 2\ \mu$ clay contains mainly mixed hydrous micas with both vermiculite and 10A illite present, as well as interlayered vermiculite and illite, mostly random but some regularly interlayered (Jackson *et al.*, 1952). Quartz and felspar are also present. The silt contains micas similar to the clay (but less of them), indicating probably that the weathered micas persist into the larger fractions. It also contains considerable amounts of quartz and felspar". Further work would be needed to establish definitely the source of the non-exchangeable reserves of potassium, but the high K_2O content of the clay and the X ray evidence point strongly to the hydrous micas of the clay and silt as the major contributors.

Discussion: It is of interest that the figures for the last three N HNO_3 extractions—particularly the third and fourth—are almost constant, at about 0.80 m.e.%, for all plots at both sampling dates. From the available data it is not possible to say just what significance this apparent equilibrium figure has; but it may well provide a good measure of potassium-supplying power—perhaps a more fundamental value than the single extraction used by some of the American workers. Such an equilibrium value has been correlated with K-supplying power (as measured by continuous cropping) by Evans and Simon (1950), who measured the potassium removed by successive extractions with 0.5 N HCl. After the second extraction, a straight line graph was obtained when the sum of the K removed was plotted against the number of extractions; the slope of the graph gave a good correlation with potassium-supplying power.

It is not possible to say how long this rate of potassium release could be maintained, but the data suggest that, since approximately 3 m.e.% of K have already been supplied (again, on the 0–3-in. basis) without measurable effect on the chemical figures, reserves

of potentially available potassium in this soil must be very high. It seems unlikely that much of this potassium could have been drawn from lower horizons of the soil. Work on experimental turf plots at Hokowhitu (Metson and Gibbs, 1946) suggested that in short periods under pasture or turf, the soil changes were most pronounced in the top inch of soil, less so in the 1–3-in. layer, and rather small at 3–6 in. Page and Williams (1925), in attempting to account for the removal, over many years, of about 900 lb. of K_2O from plots not receiving potash fertilizer, also tended to the view that the bulk of this potassium had been supplied from non-exchangeable potassium of the surface soil rather than from soil layers deeper than those analysed. In their work, however, the soil was analysed to a depth of 18 in.

It seems possible that the comparatively low exchangeable K figures—for the 1944, and 1948 N.R. analyses—may represent equilibrium figures for this soil, such as would be obtained after prolonged cropping without potash additions. This would explain the lack of change in the exchangeable K figures after removal of dung and urine. Breland *et al.*(1950) found in continuous cropping experiments that exchangeable K values dropped rapidly at first and then more gradually, "until a certain level was reached when the potassium-supplying power of the soils was determined largely by the rate at which non-exchangeable potassium was converted into the exchangeable, which was considered the form available to the plants." These final exchangeable values, however, were very low indeed, ranging from 23 to 135 lb. K_2O per 2,000,000 lb. of soil (or 0.024 to 0.14 m.e.%) for 23 Indiana soils after 8 crops of ladino clover has been removed in 493 days. The original values were from 89 to 253 lb. (or 0.095 to 0.27 m.e.%) and non-exchangeable K_2O released ranged from zero to over 1,000 lb. If the Lincoln values of about 0.4 m.e.% do represent approximate equilibrium values, then, on the basis of the work of Breland *et al.* (1950), a very high potassium-supplying power is indicated for this soil.

This result may be significant in relation to the high productivity of the N.R. plots, and a further factor—in addition to the removal of nitrogen in dung and urine—in stimulating the clovers to the extent that the soil nitrogen level has been maintained and the dry matter production of the F.R. plots equalled. It was shown by Blaser and Brady (1950), for example, that grasses and weeds have greater ability to take up potassium from the soil than clovers. This effect was particularly noticeable at low levels of soil potassium; and was accentuated by nitrogen fertilizers, which stimulated the growth of grasses and hence increased their demand for potassium. Under these conditions growth of the legumes was depressed. Blaser and Brady found, however, that potassium fertilization stimulated clover growth without directly affecting the productivity of the non-leguminous plants. According to Mattson (1949), the reason for the relatively low uptake of potassium (and monovalent ions in general) and high uptake of calcium (or other divalent ions) by legumes, as compared with non-legumes, is to be found in the much higher cation-exchange

capacities of the root systems of the former. Drake *et al.* (1951) found higher cation-exchange capacities for the root systems of a number of dicotyledons, including several legumes, than for the roots of monocotyledons; and these authors also ascribed some nutrient competition effects between different plant species, at low levels of cation concentrations, to this fact. Results of this kind, in the view of Mattson and his co-workers (e.g., Elgabaly and Wiklander, 1949), are explicable, in a general way, as valence effects due to a "Donnan distribution" of ions between colloidal systems of different sorption capacities. The ramifications of this theory need not be discussed here, but it is instructive to examine the analytical data for the herbage from the Lincoln and Palmerston North trials. Some of the results (4-year averages in each case) are illustrated in Figure 2. The close relation between the botanical composition of the herbage and its chemical composition is well shown, and is in the direction expected from what is known of the relative uptake of monovalent and divalent cations by grasses and clovers respectively.

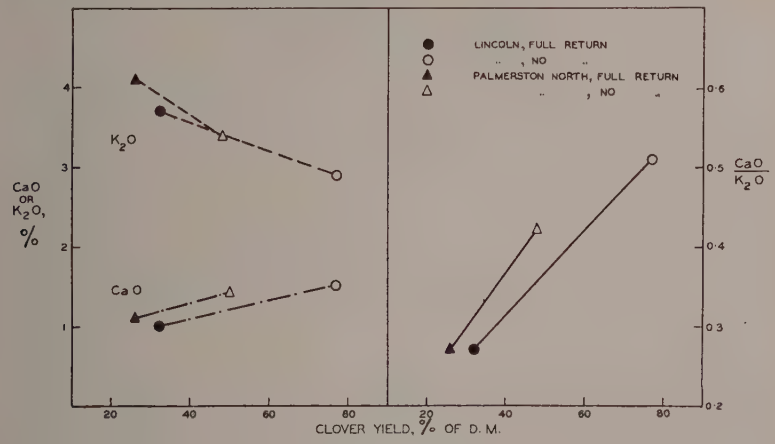


FIG. 2.—Relation of Calcium and Potassium content of Herbage to Clover Yield.

From these considerations, it seems possible that the treatments used in this Lincoln grazing experiment may have had a different result on a soil with a lower potassium-supplying power. The combined factors of nitrogen removal and high potassium status of the soil (even after allowing for losses in the urine) would be expected to provide ideal conditions for clover dominance in the N.R. plots, and, in fact, this was found. With nitrogen returned to the soil in animal excreta, and with a high potassium-supplying power of the soil, as before (but enhanced by potassium returned in the urine), conditions in the F.R. plots would be relatively more favourable to the grasses, but still not entirely unfavourable to the legumes: this would appear to be substantiated by the fairly high clover yields, under the conditions, of Plots 13 and 16 (24 and 32 per cent, respectively). In the absence of soil analyses for other

experiments of this nature these conclusions must be regarded as tentative only, but they do suggest that the soil factor may merit more detailed study in pasture production work.

Nitrogen

Nitrate and Ammonia Nitrogen:—In view of the findings of Thompson and Coup (1940a, 1940b, 1943) on the increase in soil ammonia and nitrate under pastures which had received heavy applications of stock urine, it was thought that the present experiment might show appreciable differences between F.R. and N.R. plots. Because of the small differences found at the first three sampling dates—Jan., Feb., Nov., 1945—and because of the difficulty in collecting samples, only one further sampling was made —in Feb., 1948.

The nitrogen of herbivorous stock urine consists mainly of urea N, an average figure for wether urine being 76.4 per cent N, according to Doak (1949, 1952). In the soil, urea is hydrolysed to ammonia, which is then converted by microbiological action through nitrite to nitrate. The conversion of urea nitrogen to ammonia is quite rapid, and a considerable proportion of this is then, more slowly, converted into nitrate, which is either used by the pasture or lost by leaching. These simple reactions, of course, represent only the main course of the transformations of urinary nitrogen in the soil: a detailed schematic diagram of the urinary nitrogen cycle has been given by Doak (1952, p. 170).

The results for *ammonia nitrogen* are given in Table X. The small number of samplings and the uncertainties attached to the analyses, on account of inevitable delays between sampling and analysis, detract from the results, but it would appear that the differences between F.R. and N.R. plots are neither large nor consistent. There is a tendency at the 1948 sampling date for the F.R. figures (Plots 13 and 16) to be higher than the N.R. ones, but the data are too few for the results to be conclusive. Results for *nitrate nitrogen* are not reported since no figure greater than 2 p.p.m. N was obtained. Usually, nitrate-N was less than 1 p.p.m., and no consistent differences between F.R. and N.R. plots were found.

It would appear that these results are in general accord with other work on grassland soils, in that nitrate values are very low, and ammonia values low and rather variable, but higher than the nitrate figures (Richardson, 1935, 1938; Theron, 1951). Thompson and Coup (1940a, p. 78A) found values of from 1 to 20 p.p.m. nitrate–N for a number of Waikato pasture soils, with some much higher; but, as they point out in a subsequent paper (1940b), some of these values are almost certainly too high because of the inclusion of samples from urine patches, in which the nitrate–N content may reach several hundred parts per million. Thompson and Coup (1943) further showed that stock urine or urea applied to small patches of soil very rapidly produced ammonia–N contents of several hundred p.p.m.; nitrate–N rose more slowly to high values as ammonia–N declined. Control figures under pasture were less than 10 p.p.m. for ammonia–N and about 1 p.p.m. for

TABLE X. AMMONIA NITROGEN IN DUNG AND URINE EXPERIMENTAL PLOTS, LINCOLN

Depth (in.)	DATE OF SAMPLING						Plot No.	Treatment
	February, 1945		November, 1945		February, 1948			
	Morning	Afternoon	Morning	Afternoon	Morning	Afternoon		
	Ammonia nitrogen, as p.p.m. N on oven-dry soil.							
0–1	24	25	54	23	22	23	9	N.R. High fertilizer
1–3	24	21	22	20	....	....		
0–1	24	24	30	21	12	29	12	N.R. No fertilizer
1–3	23	20	....	....	....	....		
0–1	28	65	31	47	43	47	13	F.R. High fertilizer
1–3	21	34	29	19	....	....		
0–1	51	37	26	41	46	32	16	F.R. No fertilizer
1–3	24	26	....	....	69	112		

nitrate–N. It appears, then, that very low nitrate figures and somewhat higher ammonia figures are typically found under grass. The grazing animal does not appear to influence this result except locally where urine is voided; where adequate sampling is made of a large area these local concentrations have much less effect on the average values than might have been expected.

Total nitrogen: Table XI summarises the data for total soil nitrogen in four of the plots. In some respects the nitrogen picture is similar to that of potassium, in that it involves the removal of a large quantity of nitrogen from the surface of the N.R. plots, and the turnover of a similar large quantity of nitrogen in the F.R. plots, both without much effect on the level of nitrogen in the soil. There is this difference: whereas losses of exchangeable K in the N.R. plots must have been made up from soil reserves, this explanation cannot be advanced for the maintenance of the nitrogen level because the figures are for "total N".

Total soil nitrogen has increased to a small extent on all plots except Plot 12—which received no dung and urine return and no lime and superphosphate—where the small increase is not significant. Differences between F.R. and N.R. plots likewise are of no significance (Table IV). From the data of Sears and Thurston (1953) the nitrogen removed has been calculated, and when this is added to the gain in soil N, the quantity of nitrogen which must have been supplied from all sources to account for the 1948 soil figures is obtained. This leads to the conclusion that Plot 9 has supplied nitrogen at the rate of 1,370 lb./acre in 3½ years. On the basis of a 3-in. acre of 0.7×10^6 lb. this amounts to about 0.20 per cent. The original N level is 0.24 per cent, so that nitrogen has been supplied at a rate sufficient for complete replenishment of the nitrogen content of the top 3 in. of soil within five years. On Plot 12 the pasture yield was lower, and so less nitrogen was removed. Soil N remained at the same level, which means that 970 lb./acre must have been supplied; at this rate the nitrogen of the top 3 in. of soil would have been replenished entirely in a little over six years.

During the same period, the F.R. plots show no evidence of any appreciable build-up of nitrogen or of any difference from the N.R. plots. (Tables III and IV). Admittedly there has been no actual addition of nitrogen to these plots, the treatment being an absence of the removal of dung and urine.

Discussion: The two sets of plots—F.R. and N.R.—differ in their treatments to the extent that 1,000 lb. or more of nitrogen has been removed from the latter than from the former (possible losses of N by volatilization or leaching from the F.R. plots, which would reduce this margin, have been disregarded). Analysis of the soil shows no indication of this, although the amounts involved approach the entire total N content of the top 3-in. of soil. It is of interest to consider possible sources of the nitrogen which has maintained the nitrogen level of the N.R. plots at its original figure. The nitrogen of the topsoil may be maintained or increased from the following possible sources:

(1) Nitrogen from lower soil levels taken up by plant roots and returned to the topsoil by the organic cycle;

(2) Nitrogen brought down as ammonia or nitrate in the rainfall; and

(3) Atmospheric nitrogen fixed by soil bacteria, free-living or symbiotic.

TABLE XI. NITROGEN STATUS OF TOP 3 IN. OF SOIL, BEFORE AND AFTER TREATMENT

Depth (in.)	Total Soil N 0–3 in.			Approximate Gain in Soil N in 3½ years	N removed in dung and urine in 3½ years†	Total N supplied by plot to account for soil N figure		Relative Yield†	Clover Yield†	Relative Clover Yield, i.e. Yield x % Clover / 100	Plot No.	Treatment
	1944 (%)	1948 (%)	Gain (%)	(lb./ac.)	(lb./ac.)	(lb./ac.)	(lb./ac./yr.)		(% of D.M.)			
0–1	0.23	0.31										
1–2	0.24 } 0.24	0.24 } 0.26	0.02	140	1230	1370	391	126	66.0	83.2	9	N.R. High fertilizer
2–3	0.23	0.23					Av. 334			Av. 77		
0–1	0.22	0.25										
1–2	0.23 } 0.23	0.22 } 0.23	0.00	0	970	970	277	100	70.8	70.8	12	N.R. No fertilizer
2–3	0.23	0.22										
0–1	0.23	0.31										
1–2	0.23 } 0.24	0.26 } 0.26	0.02	140	0	140	40	127	24.0	30.5	13	F.R. High fertilizer
2–3	0.24	0.22					Av. 30			Av. 32		
0–1	0.23	0.28										
1–2	0.22 } 0.23	0.23 } 0.24	0.01	70	0	70	20	105	32.1	33.7	16	F.R. No fertilizer
2–3	0.23	0.22										

† From data of Sears and Thurston (1953).

It seems unlikely that (1) can account for anything but a small proportion of the N gain of the topsoil. From the analyses (Tables II and III) it appears that a slight build-up in the 0–1-in. layer has occurred, but no depletion at the 1–2 and 2–3-in. levels. In any case it is difficult to imagine a mechanism for rapid movement of nitrogen in organic combination at lower depths into plant roots and its translocation to the topsoil, particularly in view of the estimate that less than 4 per cent of the total generally becomes available for plant use during a season (Ensminger and Pearson, 1950, p. 82). Source (2) may be dismissed immediately, as published figures indicate that only a very few pounds per acre of nitrogen are derived from the atmosphere as nitrate and ammonia; this would be the same for all plots, and would probably be counterbalanced by leaching losses. The similarity in pasture yields, too, indicates that mechanism (1), if operative to any extent, would apply almost equally to all plots. Source (3), the biological fixation of atmospheric nitrogen, must therefore be chiefly responsible for the maintenance of the soil nitrogen in the N.R. plots.

The two kinds of micro-organisms which are known to fix nitrogen are: the free-living or non-symbiotic bacteria, principally the aerobic *Azotobacter* group; and the symbiotic or nodule bacteria (*Rhizobia*) associated with the roots of leguminous plants. The *Azotobacter* are usually considered to be of limited agricultural importance, and it does not appear to be established that in soils they actually fix appreciable quantities of nitrogen (Allison, 1947; Allison *et al.*, 1947; Blair, 1951, p. 15). Moreover, soil reaction is important in limiting their distribution and activity; according to Gainey (1948), they do not survive below pH 6.0. These considerations make it very unlikely that non-symbiotic nitrogen fixation is important in this experiment.

One is forced to conclude that almost the entire nitrogen production of these plots has been due to the symbiotic nitrogen-fixing bacteria associated with the clovers. Red clover was the dominant legume, with white clover less important; on the N.R. plots, Sears and Thurston (1953) found that red clover contributed the bulk of the total production, especially in the summer and autumn periods. The F.R. plots on the other hand were dominated by the grasses. The relative yields and clover yields from their data, together with "relative clover yields" for the plots concerned, are given in Table XI. These show that the clovers in the N.R. plots produced approximately 2.4 times as much dry matter as did the clovers of the corresponding F.R. plots, although the total average annual dry matter production was the same for both series of plots. The quantity of nitrogen which must have been supplied to account for the soil nitrogen figures is approximately 334 lb./acre/year for the N.R. plots and only about 30 lb./acre/year for the F.R. plots. This would appear to indicate a greater effectiveness in nitrogen fixation by the bacteria of the plots receiving no dung and urine return, and is in agreement with what is known of the activities of the nitrogen-fixing bacteria. Where the soil is well supplied with available nitrogen (as nitrate), nitrogen fixation is less than where the soil nitrate-supply is low. (Waksman and Starkey, 1931).

From total nitrogen and ammonia figures, and from pasture yields, it would appear that the available nitrogen supply is not very different for the two series of plots. On the one hand this nitrogen must have been derived principally from animal excreta, mainly from the urea of the urine, and on the other hand it must have come from the atmosphere by symbiotic nitrogen fixation—two very different processes. It seems likely that ammonia is an intermediate stage in the utilization of either source of nitrogen: it is well established that the urea of stock urine is hydrolysed to ammonia in the soil (Thompson and Coup, 1943; Doak, 1952); and it appears to be accepted that microbiological nitrogen fixation occurs by a reduction process, via ammonia (Stephenson, 1949, pp. 233–9). The subsequent fate of this ammonia is probably quite complex, but nitrification, by way of nitrate, is certainly one of the main possible transformations. Some ammonia may be lost by volatilization at the high soil pH values resulting from the hydrolysis of urea, as pointed out by Doak; and some, probably as ammonium ions, may be absorbed by plant roots as suggested by Richardson (1935) and by Doak.

In reviewing the literature, Theron (1951) concluded that depression of nitrate formation under a plant cover appears to be a general phenomenon, particularly during the later stages of growth of the plant, and especially under a perennial grass cover. He found this to be a limiting factor in pasture production under South African conditions, where clovers will not grow. This property of plants to inhibit nitrification is seen by Theron as a natural mechanism "which maintains the humus because the plant, by paralysing the autotrophic mechanism of the nitrifying organisms, prevents the loss of nitrogen". A contributory factor to the relative accumulation of ammonia and the consistently low level of nitrate in the present study may have been the rather low pH values (5.3 to 5.9) of the soils. Doak (1952, p. 165) found that nitrification of ammonium compounds is greatly retarded at the low pH (about 5.5) of many New Zealand soils. It appears to be established that nitrification is favoured by a somewhat alkaline reaction, although acid-tolerant strains of the nitrifying bacteria evidently exist in soils (Stephenson, 1949, p. 247); and it may be significant that nitrogen production was higher in proportion to the relative clover yield in Plot 9, which received lime and superphosphate and had a final average pH of 5.9, than in Plot 12, which received no fertilizer topdressing and had a final pH of 5.3. The high pH and available phosphate of Plot 9 would be expected to favour both nitrogen fixation and nitrification processes.

It might be thought that nitrate, being the most readily available form of nitrogen to plants, is taken up immediately it is formed in the soil; and that this rapid uptake is responsible for the consistently low nitrate levels found under a pasture cover. This possibility cannot be entirely dismissed, and it must certainly be a factor in preventing accumulation of nitrate nitrogen. However, in the absence of any direct evidence of high nitrate production, and in view of the findings of other workers, it appears

unlikely that uptake by the pasture has been the main factor in keeping soil nitrate at a low level.

Waksman and Starkey (1931) state that with most legumes growth is best at reactions close to neutrality, and nodulation is greatest under such conditions. They qualify this statement, however, by observing that "those conditions most favourable to the host plants favour nodulation and nitrogen fixation" and that "some legumes are quite acid tolerant, and good nodule development occurs in acid soils". The lower pH limit for the bacteria of clovers is given as 4.2. From the results of this experiment it is evident that large amounts of nitrogen have been fixed under rather acid conditions (pH 5.2 to 5.9). If it is assumed that all of the observed nitrogen production was due to the legume bacteria (and this cannot be far from the truth), this amounts to some 391 and 277 lb. per annum in Plots 9 and 12 respectively. Clovers contributed about 66 and 71 per cent respectively of the total pasture yield, so that their absolute per acre effectiveness may be rated somewhat higher than this. These figures are higher than those given by Giobel (1926, p. 11) who quotes figures for clovers of up to 200 lb. per acre. It would appear, however, that nitrogen production on the N.R. treatment of the Palmerston North trial was even higher than at Lincoln. The drain in nitrogen at Palmerston North was given by Sears *et al.* (1948, p. 249), for an average annual pasture yield of 10,600 lb. of dry matter, as equivalent to 20.6 cwt. of sulphate of ammonia, or about 490 lb. of nitrogen. The average clover percentage was only 48, which points to a much higher effectiveness of the clovers than at Lincoln; but in the absence of soil analytical data it is not possible to calculate nitrogen production figures in detail. More favourable climatic conditions, particularly as regards moisture, would no doubt contribute to the greater nitrogen fixation at Palmerston North.

What is true for nitrogen—the maintenance of the soil level at a rather constant figure in spite of large losses—is true also for soil organic carbon. Obviously, large quantities of organic carbon must have been removed in the dung and urine from the N.R. plots, and yet these show no depletion, and indeed an appreciable build-up, of organic carbon (Tables II and III). Again there are no marked differences between N.R. and F.R. plots. The explanation of this result can also be presumed to be microbiological, since atmospheric carbon dioxide is the ultimate source of the organic carbon of the soil.

General Conclusions

In the study of soil changes average values only have been considered, which is undoubtedly why the differences found have been so unspectacular, particularly for the labile nitrogenous constituents. Had the "urine patch" only been considered in relation to the surrounding mass of soil, as some investigators have done, the differences found would no doubt have been more striking, though more transitory in nature.

When the soil analyses are considered in relation to the data of Sears and Thurston (1953) on the turnover or removal of plant

nutrient elements in the dung and urine, it is found, however, that the apparent lack of change is rather deceptive. Considering first the organic matter status, as shown by the organic carbon and total nitrogen analyses (Tables II, III and IV), it is seen that the changes are very small and practically confined to the top inch of soil. They appear to be associated with the development of a turf rather than with the return of dung and urine; they are most pronounced on the high fertilizer plots and are shown equally by N.R. and F.R. plots. During the period of the experiment a very large quantity of nitrogen (and, of course, carbon) has been removed from the N.R. plots in the dung and urine, while no such loss has occurred on the full return plots, and yet soil analysis does not show any loss of these constituents. On the other hand, the plots from which no nitrogen was removed showed no increase in comparison with the N.R. plots, and very little in comparison with the nitrogen values before grazing began. It appears from this result that this soil has a great capacity to resist changes in its organic matter content. Since no nitrogen or carbon was supplied to the N.R. plots, the only important source of these elements must have been the atmosphere and the processes of replenishment must have been exceedingly efficient microbiological ones.

The conclusions relating to the potassium figures are no less striking. From the soil analyses in Tables II, III, IV and IX, it is evident that the removal of a very large amount of potassium from Plots 9 and 12 has occurred with very little change in the exchangeable potassium figures. The F.R. plots show appreciable increases, but these are small when compared with the total turnover of potassium. Successive extractions with normal nitric acid showed no significant differences between F.R. and N.R. plots at the conclusion of the experiment. This soil may be exceptional in its potassium-suppying power—and indeed the figures as shown in Table VIII are higher than those obtained for most other New Zealand soils so far examined by this method (R. H. Arbuckle, Soil Bureau, unpublished work)—but the results seem to show that, if the nitric acid method means anything in terms of potassium-supplying power—and several American workers have reported excellent correlations—this particular soil has its original very high potassium status unimpaired after removal of up to 1,000 lb./acre of K_2O in three-and-a-half years. This may indeed be so; but one wonders how long this rate of supply could be maintained, and how other soils would react to such treatment.

In considering the figures for lime losses, it must be remembered that they refer to the top 3 in. of soil only; so that no firm conclusions can be reached about the ultimate fate of this lime. Since it was added as a topdressing and an appreciable fraction of it has already moved below the first three inches, there is no apparent reason why it should not ultimately move further down the soil profile and into the drainage waters. Other workers have reported lime losses of the same order; so that there is ample evidence that lime must be continually replenished if the desired pH level or degree of base saturation of the soil is to be maintained.

Considered as a whole, the experimental results provide an impressive demonstration of the stability and dynamic nature of this particular topsoil system. The fact that the yields on the two series of plots were identical, in spite of the differences in treatment and of the very different botanical composition of the herbage which resulted, is undoubtedly a surprising result, but it seems probable that soil factors were partly responsible for this. The original fertility level of the soil was moderately high, and in addition lime and superphosphate were applied to three of the four plots in each series; moreover, potassium-supplying power, as shown by the soil analyses, appears to be particularly high. These considerations, together with the fact that the 1948 soil analyses show few differences between F.R. and N.R. plots, make the observed results less surprising. They explain, too, why no differences were found between wheat yields on the two series of plots in the two seasons following the termination of the grazing experiment. In the Palmerston North trial (Sears *et al.*, 1948) pasture production on the F.R. plots was about 33 per cent higher than on the N.R. plots; soil and climatic conditions of course were different, and no soil analyses are available, so that no suggestion can be offered here to account for the difference in the results.

Since soil micro-organisms must play the major part in the breakdown and utilization of animal excreta, and in the maintenance of soil organic matter levels, it appears desirable that soil microbiological studies should accompany experimental work involving soil-plant-animal relationships. In the present experiment the part played by the clovers is very striking indeed, and by their agency soil nitrogen levels and pasture yields have been maintained. Whether soil nitrogen levels could have been increased, and greater pasture yields obtained, by the addition of nitrogenous fertilizers to either series of plots cannot be answered here; but in view of the reported recent trend towards the use of more nitrogenous fertilizers to the exclusion of clovers in high producing pastures in some other countries (Russell, 1950), the question is an interesting one.

Although in the light of subsequent knowledge it is apparent that the soil data are inadequate in some respects, and although it may fairly be objected that this paper poses more questions than it answers, nevertheless the results do suggest that the evaluation of relevant soil factors may greatly assist the interpretation of field experiments of this kind. The present paper, therefore, is in part an attempt to show how soil studies may be used in such work.

Experiments involving the grazing animal obviously require large experimental areas, and the cost and labour of running replicated experiments will often prove prohibitive. The variability of soils, even in carefully selected experimental areas must, however, be considered in planning such work, and to obtain the best results from field experiments and associated soil studies the following conditions should be observed, as far as is practicable:

(1) A detailed soil survey of the area should be made before the commencement of the experiment proper.

(2) Soil chemical analyses, by carefully standardized methods, for all the constituents considered to be relevant to the purpose of the experiment, should be made before treatments are begun. The depth to which samples are to be taken should be carefully considered. Under pasture, soil changes are greatest in the top inch of soil, and usually not very pronounced below three inches. Nevertheless, samples below this are useful in assessing gains or losses of the various nutrient elements. This naturally increases the labour of taking adequate samples and involves a great deal of analytical work, so that a compromise must usually be made.

(3) If possible, microbiological studies should supplement the botanical and chemical work.

(4) If possible, sufficient replicates should be made for the experimental errors to be estimated.

(5) The experiment should be of sufficient duration for the effects of the treatments to be adequately measured.

These are difficult and expensive conditions to fulfil; but unless they are, the full potential value of such experiments may not be realized.

ACKNOWLEDGEMENTS

The authors are indebted to Mr. P. D. Sears of the Grasslands Division for the invitation to take part in this investigation, and for much subsequent co-operation and assistance; to Mr. W. G. Thurston of the Grasslands Division and to officers of the Crop Research Division for their willing assistance in collecting the soil samples; to Messrs. C. S. Harris and C. G. Vucetich of the Soil Bureau, Christchurch, for the soil survey of the area, for assistance with the sampling, and for valuable liaison work; and finally to Messrs. G. D. Gemmell, W. B. Healy, and R. H. Arbuckle, who assisted with the chemical analyses, and Mr. M. Fieldes who examined the silt and clay samples by the X-ray method.

REFERENCES

ALLISON, F. E., 1947: Azotobacter inoculation of crops: I. Historical. *Soil Sci. 64*: 413-29.

ALLISON, F. E.; GADDY, V. L.; PINCK, L. A.; ARMIGER, W. H., 1947: Azotobacter inoculation of crops: II. Effect on crops under greenhouse conditions. *Ibid. 64*: 489-97.

ATTOE, O. J.; TRUOG, E., 1946: Exchangeable and acid-soluble potassium as regards availability and reciprocal relationships. *Proc. Soil Sci. Soc. Amer. 10*: 81-6.

BLAIR, I. D., 1951: Micro-organisms and plant growth. Lincoln Coll. Tech. Publ. No. 5. 42pp.

BLASER, R. E.; BRADY, N. C., 1950: Nutrient competition in plant associations. *Agron. J. 42*: 128-35.

BRAY, R. H.; DETURK, E. E., 1939: The release of potassium from non-replaceable forms in Illinois soils. *Proc. Soil Sci. Soc. Amer. 3*: 101-6.

BRELAND, H. L.; BERTRAMSON, B. R.; BORLAND, J. W., 1950: Potassium supplying power of several Indiana soils. *Soil Sci. 70*: 237-47.

DAVIES, E. B.; COUP, M. R.; THOMPSON, F. B.; HANSEN, R. P., 1940: Studies on nitrate and ammonia in soils under permanent pasture. I. The stabilization of nitrate in soil samples. *N.Z. J. Sci. Tech. 21*: 348A-51A.

DAVIES, W. M., 1938: The problem of liming in relation to soil acidity. *Agric. Prog. 15*: 111-8.

DIXON, J. K.; TAYLOR, N. H., 1942: Losses of exchangeable potash and magnesia contents from Waikato soils following continued phosphate topdressing. *Ibid. 24*: 146A-51A.

DOAK, B. W., 1941: Movement and loss of lime from a soil under pasture. *Ibid. 22*: 263A-78A.

———— 1949: The fate of nitrogenous constituents in animal excreta when voided on the soil. *Proc. Brit. Comm. Sci. Off. Conf. Spec. Conf. Agric. Aust.* pp. 418-23.

————, 1952: Some chemical changes in the nitrogenous constituents of urine when voided on pasture. *J. Agric. Sci. 42*: 162-71.

DRAKE, M.; VENGRIS, J.; COLBY, W. G., 1951: Cation exchange capacity of plant roots. *Soil Sci. 72*: 139-47.

ELGABALY, M. M.; WIKLANDER, L., 1949: Effect of exchange capacity of clay mineral and acidoid content of plant on uptake of sodium and calcium by excised barley and pea roots. *N.Z. J. Sci. Tech. 67*: 419-24.

EVANS, C. E.; SIMON, R. H., 1950: Non-exchangeable potassium removal from soils by successive acid extractions as related to removal by greenhouse crops. *Proc. Soil Sci. Soc. Amer. 14*: 126-30.

ENSMINGER, L. E.; PEARSON, R. W., 1950: Soil nitrogen. In "Advances in Agronomy" 2: 81-111. Academic Press Inc., New York, 407 pp.

GAINEY, P. L., 1948: The significance of available calcium as a factor limiting growth of Azotobacter at pH levels below 6.0. *J. Agric. Res. 76*: 265-70.

GIOBEL, G., 1926: The relation of the soil nitrogen to nodule development and fixation of nitrogen by certain legumes. *New Jersey Agric. Exp. Sta. Bull. 436*: 125 pp.

HOOVER, C. D.; JONES, V. S.; GHOLSTON, L. E., 1949: Release of non-exchangeable potassium as influenced by weathering, soil mineral type, soil reaction and potassium fertilization. *Proc. Soil Sci. Soc. Amer. 13*: 347-51.

JACKSON, M. L.; HSEUNG, Y.; COREY, R. B.; EVANS, E. J.; VANDEN HEUVEL, R. C., 1952: Weathering sequence of clay-size minerals in soils and sediments. II. Chemical weathering of layer silicates. *Ibid. 16*: 3-6.

MATTSON, S., 1948: Laws of ionic exchange. III. Donnan equilibria in plant nutrition. *Ann. Roy. Agr. Coll. Sweden 15*: 308-316.

METSON, A. J., 1953: Methods of Chemical Analysis for New Zealand Soils. *N.Z. Soil Bur. Bull.* (in preparation).

METSON, A. J.; GIBBS, H. S., 1946: Effect of manurial treatments on soil properties at the Hokowhitu Experimental Plots, and some practical applications. *N.Z. J. Sci. Tech. A27*: 413-26.

MORGAN, P. G., 1919: The limestone and phosphate resources of New Zealand, Part I, Limestone. *N.Z. Geol. Surv. Bull. n.s. 22*: 316 pp.

PAGE, H. J.; WILLIAMS, W., 1925: Studies on base exchange in Rothamsted soils. *Trans. Faraday Soc. 20*: 573-85.

PRATT, P. F., 1952: Release of potassium from non-exchangeable forms from size fractions of several Iowa soils. *Proc. Soil Sci. Soc. Amer. 16*: 25-9.

REITEMEIER, R. F., 1951: Soil Potassium. In "Advances in Agronomy," Vol. 3: 113-64. Academic Press Inc., New York, 361 pp.

REITEMEIER, R. F.; BROWN, I. C.; HOLMES, R. S., 1951: Release of native and fixed nonexchangeable potassium. *U.S. Dept. Agric. Tech. Bull. 1049*. 46 pp.

RICHARDSON, H. L., 1935: The nitrogen cycle in grassland soils. *Trans. 3rd. Int. Congr. Soil Sci. 1*: 219-21.

RICHARDSON, H. L., 1938: The nitrogen cycle in grassland soils, with especial reference to the Rothamsted Park Grass Experiment. *J. Agric. Sci. 28*: 73-121.

ROUSE, R. D.; BERTRAMSON, B. R., 1950: Potassium availability in several Indiana soils: its nature and methods of evaluation. *Proc. Soil Sci. Soc. Amer. 14*: 113-23.

RUSSELL, E. W., 1950: Soils and fertilizers. *J. Roy. Agric. Soc. England, 111*: 140-54.

SEARS, P. D.; NEWBOLD, R. P., 1942: The effect of sheep droppings on yield, botanical composition and chemical composition of pasture. I. Establishment of trial, technique of measurement, and results for the 1940-41 season. *N.Z. J. Sci. Tech. 24*: 36A-61A.

SEARS, P. D.; GOODALL, V. C.; NEWBOLD, R. P., 1948: The effect of sheep droppings on yield, botanical composition and chemical composition of pasture. II. Results for the years 1942-1944 and final summary of the trial. *Ibid. A30*: 231-50.

SEARS, P. D., 1949: The effects of legumes, fertilizers, and the grazing animal in pasture production. *Proc. Brit. Comm. Sci. Off. Conf. Spec. Conf. Agric. Aust.* pp. 409-18.

SEARS, P. D.; THURSTON, W. G., 1953: Effect of sheep droppings on yield, botanical composition and chemical composition of pasture. III. Results of field trial at Lincoln, Canterbury, for the years 1944-1947. *N.Z. J. Sci. Tech. A34*: 445-59.

ELASTRATION AND OTHER METHODS OF CASTRATION IN RELATION TO CARCASS QUALITY OF FAT LAMBS

By D. E. Walker, Ruakura Animal Research Station, New Zealand Department of Agriculture, Hamilton

(Received for publication, 4 August 1953)

Summary

1. The carcasses of lambs castrated by various methods, and also of entire lambs, have been critically examined and compared.

2. No differences were found in carcass weights, measurements or proportions between the various groups.

3. The carcass grading of the castrated groups was similar, but the entire lambs were inferior in this respect, owing to poorer fat development.

4. From the carcass aspect, the method of castration used appears to be immaterial, as long as the operation is cleanly and efficiently carried out.

Introduction

Although there has been a certain amount of controversy amongst farmers over different methods of castration, there has previously been little incentive for those interested in technical and practical aspects of the meat trade to enter into argument. As long as the operation was carried out cleanly and efficiently, little reason for criticism was apparent when the animals were eventually marketed. Such investigations as have been carried out on lambs have been concerned chiefly with the growth rate of animals castrated by knife and by emasculator. Ewer and Hancock[1] found no difference in growth rate or carcass grade in lambs in New Zealand castrated by these two methods, thereby confirming the results of Garner and Sanders[2] in England.

Some twelve years ago the new method of "Elastration" was introduced, and soon became very popular. This method consists of the application of a tight rubber ring round the neck of the scrotum, which causes the testicles to atrophy and, eventually, the scrotum to drop off. Some trade criticism was evoked by this method. Smithfield judges of the New Zealand Meat Board's Fat Lamb Competition contended that lambs castrated by the use of rubber rings showed "staggy" characteristics. They also objected to the protrusion of the last tail vertebra when the rubber rings had also been used for tailing. With the object of examining the validity of these contentions and also of comparing the carcasses produced by other standard methods, a trial was carried out in the 1950-51 season. As sufficient lambs were not available at Ruakura, a neighbouring farmer provided facilities. The property concerned was first-class fat lamb country.

Experimental Procedure

A flock including 320 male lambs was made available. These lambs were all born within a five-day period and were run together

in a 200-acre paddock from lambing till drafting. Three methods of castration were used, the instruments employed being the elastrator, knife and emasculator. Approximately one fifth of the lambs were castrated at birth using the elastrator. This group was included mainly for experimental information. For some years it was the practice at Ruakura, and other centres where lambs have to be identified at birth, to castrate and tail them at the same time. Preliminary work with beef cattle[3] has indicated that early castration may retard growth. This group of lambs was therefore included to enable a comparison to be made. At the other extreme, a group of lambs was left uncastrated to permit comparison for "stagginess". Obviously, if "stagginess" is found in castrated lambs it should be even more pronounced in lambs left entire. In a previous Ruakura trial[4] involving a group of ram lambs, meat experts criticised the carcasses as being too coarse or "staggy".

The main docking was carried out when the lambs were three weeks old. The following groups resulted from the methods of castration used:

(1) With elastrator at birth
(2) With elastrator at age of 3 wk.
(3) With knife at age of 3 wk.
(4) With emasculator at age of 3 wk.
(5) Uncastrated.

In order not to confuse the issue, all tailing was done by knife. This seems to be a common procedure, even when rings are used on the scrotum. As docking was carried out under farm conditions and the flock handled was large, it was not possible to weigh the lambs and allot them to their respective groups. Lambs were caught at random and assigned to each group in turn as they were presented.

As defined by the British meat experts, the "stagginess" complained of consisted of excessive weight in the forequarters, large heavy scrags, and excessively wide hindquarters. To obtain the necessary data for carcass evaluation and to cover these points, carcass weights and grades were recorded and detailed standard measurements were taken on all carcasses (Fig.1). In addition, 10 carcasses from each group were jointed into standard English cuts by a professional butcher and carcass judge, and the weights of fore-end, middle and hind-end obtained. These carcasses were carefully selected as most closely approximating the average of the line in weight, grade and measurements.

RESULTS

Carcass Weights and Measurements

Mean carcass weights and measurements for all drafts are shown in Table I.

The weight and measurment differences between the various groups are not significant. However, it is interesting to note

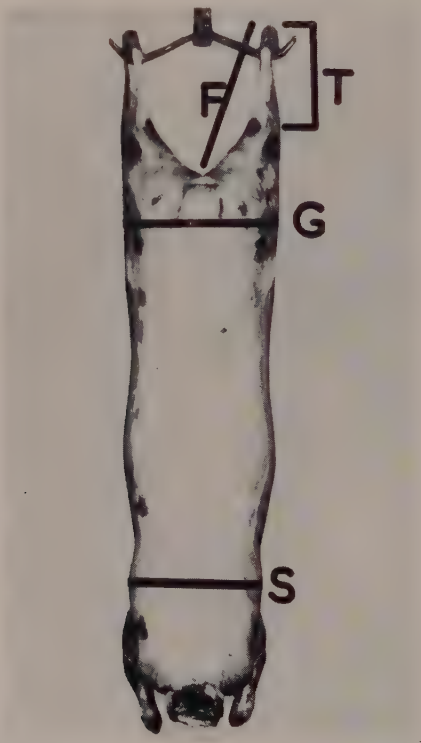


FIG. 1.—Standard Method of Recording Carcass Measurements.

TABLE I. CARCASS WEIGHTS AND MEASUREMENTS

Method of Castration	Weight (lb.)	F	T	G	S	% in First draft
Elastrator at birth	36.5	228.2	171.7	229.2	196.4	73
Elastrator at 3 wk.	37.7	230.4	173.0	231.7	197.0	65
Knife at 3 wk.	37.0	229.8	173.2	230.2	196.8	69
Emasculator at 3 wk.	37.8	229.5	173.6	231.3	198.3	69
Uncastrated	37.7	233.0	173.1	232.4	192.2	85

that the ram lambs tended to be narrower rather than wider (or "coarse") across the shoulders (S) than the other groups. This would not be expected in carcasses showing "staggy" characteristics.

Contrary to previous findings[4], the ram lambs were no heavier than the castrated lambs. This may be explained by the fact that a higher percentage of ram lambs were sent away in the first draft owing to unnecessary apprehension on the part of the farmer

and the picker as to their future prospects. The differences between the other groups in respect to drafting percentages were not significant.

Grading

Grading results are shown in Table II.

TABLE II. GRADING PERCENTAGES

Method of Castration	Down Cross	Prime Crossbred	Second
Elastrator at birth	67	26	7
Elastrator at 3 wk.	67	33	0
Knife at 3 wk.	66	31	3
Emasculator at 3 wk.	58	34	8
Uncastrated	45	44	11

The differences in grading between the first four groups were negligible. The ram lambs did not grade as well as the other lambs, which was mainly due to lack of finish. Entire males do not lay on fat to the same extent as castrates. This aspect has been discussed in a previous paper[4].

Relative Proportions

Five 2's (i.e., under 36 lb.) and five 8's (37–42 lb.) were selected for jointing. Each carcass was cut through behind the 5th rib and at the lumbar-sacral junction, giving the standard shoulders, middle and legs as cut in commercial practice. The three parts of each carcass were weighed. Table III shows the proportions of each part relative to the total carcass weight.

TABLE III. JOINT WEIGHTS AS PERCENTAGE OF TOTAL CARCASS WEIGHT

Method of Castration	Fores	Middles	Hinds
Elastrator at birth	34.6	32.7	32.5
Elastrator at 3 wk.	35.3	32.2	32.3
Knife at 3 wk.	35.1	32.2	32.4
Emasculator at 3 wk.	35.6	31.4	32.9
Uncastrated	35.7	31.8	32.3

As with the carcass measurements, there was no significant difference in the body proportions. All groups were remarkably similar.

The five 37–42-lb. lambs (8's) elastrated at three weeks and the five corresponding ram lambs which were jointed are shown in Figs. 2 and 3.

Fig. 2. Carcasses of lambs elastrated at three weeks.

Fig. 3.—Carcasses of ram lambs.

FIG. 4.—"Staggiest" carcasses from each Group.
From left: Elastrator at birth; Uncastrated; Knife at 3 wk. Elastrator at 3 wk.; Emasculator at 3 wk.

A competent meat judge could find little fault in either group, except for a slight tendency of the ram lambs to show a heavier "scrag" or neck. The "staggiest" carcass from each group was also selected by the same judge. These carcasses are shown in Fig. 4. They are wide in the hindquarters and shoulders and thick in the scrag, but generally give the appearance of being full of meat and would normally be considered good type carcasses by the local trade, with the exception of the middle carcass, which is more of a Romney type. This type is quite commonly found amongst any line of Southdown x Romney lambs.

GENERAL OBSERVATIONS

(1) *Mortality*

Although this aspect has little direct bearing on the matter

TABLE IV. DEATHS AFTER DOCKING

Method of Castration	No. died
Elastrator at Birth	2
Elastrator at 3 wk.	1
Knife at 3 wk.	2
Emasculator at 3 wk.	—
Uncastrated	2

under investigation, a record of deaths was kept as a check on whether a heavier mortality occurred from the use of any one method. Mortality was light and no differences were apparent. The actual numbers are given below.

(2) *Disease*

This subject was also somewhat outside the scope of the investigation, but a few general observations may be made. Apart from infections caused by dirty methods, three main troubles are frequently associated with docking. These are:

(a) *Arthritis*: The organism responsible may gain entry through a wound. Only two lambs in this flock were affected, and they were from different groups.

(b) *Tetanus*: The use of the elastrator has fallen into disrepute in some districts where tetanus is prevalent. No cases were found in any group.

(3) *Fly strike*: Late lambs castrated by elastrator are generally considered to be more prone to fly strike than those docked by other methods. Docking was carried out on 20 August, when fly trouble is seldom experienced.

Discussion

Close inspection of the complete line of lambs, sorted out into their respective groups, did not reveal any differences in quality between the groups of castrated lambs. The entire lambs were inferior by Meat Board standards. This aspect of the work was carried out by Mr. C. H. Kneebone, one of the most experienced fat-lamb judges in New Zealand, who had recently had the advantage of personal consultation and experience on Smithfield Market in the judging of New Zealand export competition lambs.

Observations were made on some minor points which have aroused trade comment on lambs castrated with the elastrator.

(1) In some cases the cord and associated blood vessels, which normally wither away when castration is done by knife, were still present in the scrotal fat. However, since these tissues are not secretory, they can have had no effect on body conformation, and the only importance that can be attached to their presence lies in the very slight blemish they cause. The presence of atrophied testicles in the emasculated lambs could be a more serious cause for complaint.

(2) Less scrotal or "cod" fat was present in elastrated lambs. From the consumers' point of view this would probably be construed as an advantage, since our Down Cross lambs are generally overfat. "Cod" fat in a lamb is not particularly desirable, as it does not overlie muscle, where it could be beneficial in cooking.

(3) When the method is inefficiently used, one or both testicles may be retained. This may also occur with the emasculator. No method can be quite as certain as the knife in this respect, but a careful operator should have few failures with either instrument.

(4) Though tailing was all done by knife in this experiment, observations were made concurrently, on a different line of lambs, on the effect of using rings on the tails. Where a caudal vertebra is bisected by either a rubber ring or the knife, there is apt to be a protrusion of bone uncovered by fat. This occurs more commonly when rings are used. The blemish caused is slight and purely aesthetic. It should be noted that the practice of using rings on the tails was never suggested by the originators of the method of castration and is not a practice adopted by many farmers. A method involving immediate amputation of the tail is generally favoured as being tidier and also as having the practical advantage of allowing accurate counts to be kept.

On the major issue, as far as this study has been able to determine, no harmful effects on carcass quality were associated with the efficient application of any of the methods used. In weights, grades and carcass measurements, elastrated lambs compared favourably with those castrated by the older methods, and no difference could be detected in the proportions of the various parts of the carcass.

ACKNOWLEDGEMENTS

Thanks are due to the farmer (who prefers to remain anonymous) who made available the lambs and facilities for this investigation. Without his interested and active co-operation the work could not have been carried out. The author is also indebted to the Auckland Farmers' Freezing Company, Horotiu, for facilitating the collection of post-slaughter data, and particularly to Mr. C. H. Kneebone, of the above Company, who devoted much time and consideration to the appraisal of the various groups of carcasses and personally jointed the required bodies. As he can be credited with being the most experienced meat judge in New Zealand, his participation endows this work with certain authority.

REFERENCES

1. EWER, T. K.; HANCOCK, J. J., 1946: The Mowat Lamb Tailer. *N.Z. J. Agric. 72*: 17.

2. GARNER, F. H.; SANDERS, H. G., 1936: The effect of different methods of castration and docking on the growth of lambs. *J. Agric. Sci. 26 (2)*: 296.

3. WALKER, D. E.: Unpublished data.

4. WALKER, D. E., 1950: The influence of sex upon carcass quality of N.Z. fat lamb. Part I. *N.Z. J. Sci. Tech. A32 (1)*: 30-8.

"CLOUD" OR VASCULAR BROWNING IN TOMATOES

III. SOME OBSERVATIONS ON LEAVES AND FRUIT OF CLOUD-SUSCEPTIBLE PLANTS

By E. B. Kidson* and D. J. Stanton, Cawthron Institute, Nelson

(Received for publication, 24 August 1953)

Summary

Leaves were found to vary in dry-matter percentage with position on the plant and time of sampling.

Confirmation has been obtained of a lowered dry-matter percentage in the leaves of cloud-susceptible plants on a heavily watered plot.

Fruit varied in the time between setting and ripening from 9 to more than 15½ weeks.

Fruit on a heavily watered plot reached the low level of 4.4 per cent dry-matter a month from setting.

The damage to the vascular system characteristic of cloud appeared to be associated with changes taking place in the fruit as it began to ripen on the plant.

Fruit picked green from cloud-susceptible plants showed little cloud when ripened off the plant, but was of poor colour and texture compared with normal fruit ripened in the same way.

Introduction

"Cloud," a form of blotchy-ripening, has been described in a previous paper of this series[1]. Areas of green or brownish-green, with underlying brown veins, appear on the ripening fruit. The necrosis affects the vascular system and surrounding parenchyma cells. Corkiness and hollowness of the fruit are often found with cloud and appear to be produced by similar conditions. Corky fruit has light-coloured veins, dry in appearance, associated with the vascular tissue.

Cloud-susceptible plants have shown a low percentage of dry-matter in fruit and leaves[2]. This paper gives an account of further observations on dry-matter in relation to cloud. The possibility of a leaf test to diagnose susceptibility to the disorder has been examined. Certain changes taking place in the developing fruit on cloud-susceptible plants have been followed.

Experimental Procedure

For the determination of dry-matter in leaves the samples were placed immediately in stoppered bottles in which they were weighed. When comparing treatments, care was taken to confine sampling to the shortest possible time. In order to avoid too much damage to the plant, leaflets only were used for the estimation of dry matter. They were removed close to the main mid-rib. It was found that leaflets near the base of the leaf showed bigger differences in percentage dry-matter between cloud and healthy plants than did the terminal leaflets, and for this reason the former were normally used for comparison. All samples were dried at 100°C (approx.).

* Officer of the Department of Scientific and Industrial Research.

For experiments with fruit of known age the fruits were marked as the flower faded or within a few days of this time, by a piece of wool tied loosely round the stem. The variety used was potentate.

RESULTS

Leaves

Variation in Dry-Matter with Time of Sampling

Analyses have shown that the percentage of dry-matter in leaves may vary according to the time of sampling. In Table I the dry-matter figures for leaflets taken early on a dull, cold day are compared with those for corresponding leaflets taken at 2 p.m. on the hot, sunny day which followed. Figures are given for a heavily-watered, cloud-susceptible plot (B8) and a comparatively cloud-free plot which had been given extra nitrogen (C1). On each date, the 5th leaf from the top was sampled on alternate plants. Each sample represented 15 to 18 plants.

TABLE I. VARIATION IN PERCENTAGE DRY-MATTER OF LEAFLETS WITH TIME OF SAMPLING

Leaflets sampled		23/10/52 9 a.m. Cold dull day	24/10/53 2 p.m. Hot sunny day	Difference
Plot B8	3 end leaflets	9.8	11.3	1.5
	2 large leaflets near base of leaf	9.1	10.6	1.5
Plot C1	3 end leaflets	11.2	12.4	1.2
	2 large leaflets near base of leaf	10.9	12.0	1.1

It will be seen (Table I) that on these two dates the differences in dry-matter due to different times of sampling were of the same order as differences between treatments. Two factors are probably operative. The water content of the leaves may have been reduced by increased transpiration during the hot day. Also, on the second date there may have been an increased carbohydrate content after some hours of sunshine. The results show that from the point of view of dry-matter percentage, leaf samples may not be comparable unless sampled at the same time.

Variation in Dry-Matter with Position on the Plant

The percentage dry-matter was found to be high in young leaves and considerable differences occurred according to age and position on the plant as may be seen from Table II. Each column represents a single plant from a good plot (B2), or a cloud-susceptible plot (B8). The two large leaflets near the base of the leaf were sampled from each position.

TABLE II. VARIATION IN DRY-MATTER WITH POSITION ON THE PLANT

Position of leaf from top of plant	Percentage dry-matter on date tested					
	6/10/52		7/10/52		8/10/52	
	Plot B2	Plot B8	Plot B2	Plot B8	Plot B2	Plot B8
3rd leaf	16.8	14.5	—	—	14.6	12.1
5th leaf	13.6	12.3	13.2	11.0	12.1	10.0
7th leaf	11.5	10.5	11.1	10.8	10.9	10.5
9th leaf	11.3	9.8	10.5†	9.0	9.8	9.8
11th leaf	—	—	12.5	9.3*	9.5†	8.8
13th leaf	—	—	—	—	11.0	8.8†

† 1 above bottom bunch
* 1 below bottom bunch

The young leaves showed a steady drop in percentage dry-matter with increasing maturity (Table II). At the time of sampling the dry-matter appeared to decrease to a minimum in the leaves near the lowest bunch. There were indications that the percentages rose again in leaves nearer the base of the plant.

Variation in Percentage Dry-Matter of Leaves from Plant to Plant with the Same Treatment

In Table III are given figures for leaflets from a number of plants in Plots B8 (extra water), B2 (extra N) and C1 (extra N). In each plant the two large leaflets near the base of the 5th leaf from the top of the plant were used for the test. The samples were collected in fine weather between 11 a.m. and 11.30 a.m.

The results in Table III show some variation within the plots and the desirability of sampling as many plants as possible in determining the dry-matter status of the plot. The average figures from sampling six or seven plants, however, does show significant differences in dry-matter between Plot B8 which had much cloud (10.7 per cent dry-matter) and Plots B2 and C1 which were almost free from the disorder (11.6 per cent and 12.1 per cent respectively).

The results in Tables I, II and III confirm previous indications of a lowered percentage of dry-matter in the leaves as well as in the fruit in cloud-susceptible plants. However, in view of the fact that leaves are so variable in percentage dry-matter with position on the plant and with time of sampling, it is difficult to fix any particular level as associated with cloud. Furthermore, larger differences in dry-matter content appear to occur in fruit than in leaves. The usefulness of a leaf test is therefore limited.

TABLE III. VARIATION IN PERCENTAGE DRY-MATTER OF LEAFLETS FROM PLANT TO PLANT WITH THE SAME TREATMENT

Plant	Percentage dry-matter at date tested		
	Plot B8 10/10/53	Plot B2 9/10/53	Plot C1 10/10/53
1	10.9	11.2	11.3
2	10.6	10.9	12.2
3	10.6	12.3	12.7
4	10.3	11.2	12.7
5	10.7	11.9	11.6
6	10.8	12.3	12.0
7	—	—	11.7
Average	10.7	11.6	12.1
Range	10.3–10.9	10.9–12.3	11.3–12.7
Probable error of mean	0.06	0.2	0.1

Fruit

Variation in Time of Ripening

Fruit varied widely in the time taken to come to maturity. An examination of fruit which set between the end of September and the end of October showed that it took from 9 weeks to more than 15½ weeks to ripen. Fruit near the top of the bunches, i.e., near the main stem, appeared to be the quickest to mature. Some fruits seemed to come to a temporary halt in development and begin to grow again later when the crop had been considerably reduced by picking. Similarly, fruits 8 to 8½ weeks from setting, picked to ripen on the bench, varied considerably in the time taken to show colour. Some ripened almost immediately. Others were still quite green 17 days after picking.

Variation in Dry-Matter Percentage of Fruit from Plant to Plant with the Same Treatment

Figures are given in Table IV for fruits of the same age from different plants with the same treatment.

Samples B17 and B8 show a fairly consistent percentage of dry-matter in fruits from different plants (Table IV). Some differences might be expected owing to the variation in stage of development which can occur in fruits of the same age. Plot C1 had been given a dressing of 4 oz. of nitrogen fertilizer per sq. yd.

TABLE IV. VARIATION IN DRY-MATTER PERCENTAGE IN FRUITS OF THE SAME AGE FROM PLANT TO PLANT WITH THE SAME TREATMENT

	Percentage dry-mater at age tested		
	Plot B17 Age: approx. 49 days	Plot C1 Age: approx. 10 days	Plot B8 Age: approx. 10 days
	6.0		
	5.4		
	5.3		
	5.1		
	5.4		
	5.3		
	5.1		7.2
	5.1	7.7	7.2
	5.2	8.3	7.2
	5.7	8.1	7.2
	5.6	7.5	6.8
	5.4	7.4	7.4
Average	5.4	7.8	7.2
Range	5.1–6.0		
Probable error of mean	0.05		

only 15 days previously, a treatment expected, from the results of previous experiments, to raise the dry-matter percentage in the fruit. At this early stage some uneven effect of the fertilizer may have been possible.

Changes in Percentage Dry-Matter with Age

Fruit was sampled at different periods from the time of setting to determine the changes taking place in dry-matter percentage. The samples usually consisted of 15 to 20 fruits, one per plant. Fruits from a heavy-watering plot (B8), very susceptible to cloud, were compared with fruit from C1 where the disease had been almost eliminated by the use of extra mineral fertilizers high in nitrogen and potash.

Previous analyses have shown that the dry-matter may be from 7 to 9 per cent in the first week, after which it drops fairly rapidly. It will be seen from Table V that in the heavily watered plots the dry-matter can reach a figure associated with cloud (less than 5 per cent) in a month or less. The cloud-free plot C1 showed a higher level throughout. It is not yet known whether fruit which at about a month after setting shows an abnormally low dry-matter content of less than 5 per cent can be brought back to normal by restricting the water intake of the plant, or whether

TABLE V. CHANGES IN PERCENTAGE DRY-MATTER WITH AGE OF FRUIT

	Percentage dry-matter of fruit at indicated number of days (approx.) from fruit setting										
	12	17	23	30	33	39	45	48	51	55	69
Set 4/10/52											
B8	—	5.8	—	4.4	—	—	4.6	—	—	4.1	3.8
C1	—	6.2	—	6.0	—	—	5.5	—	—	5.8	5.5
Set 14/10/52											
B8	6.4	—	4.6	5.4	—	5.1	—	—	3.8	—	—
C1	7.7	—	6.6	6.6	—	—	—	—	—	—	—
Set 30/10/52											
B8	—	—	—	—	4.3	—	—	3.8	—	—	—
C1	—	—	—	—	6.7	—	—	5.1	—	—	—

fruit such as that produced in plot C1 (Table V) may be made to develop cloud by heavy watering in the last stages before ripening. That the latter is true seems likely. For instance, fruit sampled from B17 (Table IV), later to develop a large proportion of cloud, gave an average figure of 5.4 per cent at approximately 49 days after setting, which is higher than the figure normally associated with cloud.

Age of Fruit Showing Cloud and Cork

Observations were made on fruit of known age for the first appearance of cloud and cork. Cloud seemed to develop on fruit as it approached maturity. The earliest traces were found on fruit 50–55 days old which appeared to be only a few days from ripening. None was found in younger fruit. Cork appeared much earlier and was found on fruit about 30 days from setting on the heavy-watering plot B8.

Effect on Cloud and Cork of Ripening Fruit off the Plant

Fruit of known age was picked a few days before the observed shortest time of ripening (8½–9 weeks) and allowed to ripen indoors in the shade. It was examined carefully for signs of cloud at picking, and cut for the indentification of cloud and cork on ripening. The number of fruits affected by these disorders was compared with the amount found in fruit ripened on the plant.

Results for the heavy-watering plot B8 are shown in Table VI. Cloud and cork are expressed as number of affected fruits per cent.

Cloud was worse on fruit allowed to ripen on the plant than on fruit picked green (Table VI). The fruits picked green on 2/12/52 which showed 30 per cent cloud when ripened off the

TABLE VI. EFFECT OF RIPENING OFF THE PLANT ON CLOUD AND CORK

	Date picked	Date examined	Number of fruits	Cloud (%)	Cork (%)	Average weight per fruit (as picked) (g)
Fruit set 4/10/52						
Picked green	25/11/52	15/12/52	32	3	84	69
Picked green	2/12/52	15/12/52	20	30	90	—
Picked ripe	8/12/52 and 15/12/52	as picked	73	45	68	79
Fruit set 17/10/52						
Picked green	16/12/52	29/12/52	26	12	85	84
Picked ripe	22/12/52 and 29/12/52	as picked	28	21	54	84
Fruit set 30/10/52						
Picked green	23/12/52	6/1/53	33	3	85	87
Picked ripe	29/12/52 and 5/1/53	as picked	85	28	29	97

plant already had this amount at picking. They were at a more advanced state of maturity than the sample of 25/11/52. No cloud appeared to develop in green fruit after picking. It seems that cloud is associated with changes taking place on the plant during ripening. The "cork" which developed in so many fruits ripened on the bench was slight. It had a dry appearance resembling the cork in normally-ripened fruit. Whether the two forms of cork are identical cannot be definitely stated. The fruit picked green lost 4 to 6 per cent of weight during ripening.

Fruit off the cloud-susceptible heavy-watering plot B8 when ripened on the bench was of very poor appearance though comparatively free from cloud. It was of poor colour and texture compared with normal fruit ripened in the same way.

REFERENCES

1. KIDSON, E. B.; STANTON, D. J., 1953: *N.Z. J. Sci. Tech. A34*: 521-30.
2. ————, 1953: *Ibid. A35*: 1-14.

PRODUCTION OF HONEY MEAD FROM NEW ZEALAND HONEYS

By T. Palmer-Jones, Animal Research Station, Wallaceville

(Received for publication, 26 August 1953)

Summary

An historical account of mead is given. Experiments were carried out to examine the possibility of producing mead on a commercial scale from local honeys which are not readily saleable unblended because of their strong flavour or dark colour, or both these characteristics. A satisfactory method was worked out and commercial production should be straightforward as the plant required is relatively inexpensive. Consumer tests indicated a preference for manuka meads. Pleasant meads, however, were produced from all honeys except that from buttercup.

It is considered that alcohol from meads when treated with activated charcoal would be very suitable for gin production. One ton of manuka honey, costing at present £72 6s. 8d., would yield approximately 60 gal. of absolute alcohol, and 900 bottles of gin.

Introduction

In early Egyptian and Roman times mead was freely drunk. But as forests were felled the wild bee population declined and the honey used in mead making became scarcer. So mead was gradually replaced by wine and beer, and by later Roman times was regarded as a luxury to be used on great occasions and for pouring libations to the gods. The same process took place subsequently in England and Scandinavia, but in the Ukraine and Poland mead was a popular drink at least until 1939.

In Anglo-Saxon times mead was highly regarded and widely drunk and there are many references to it in contemporary literature. Mead in England retained some of its dignity right up to the time of Charles II who had a royal mead maker. However, since the Norman Conquest a taste for wines, particularly sweet wines, developed, and sweet meads became preferred. Sweet meads cannot equal dry meads in flavour and hence meads lost their appeal to the connoisseur. Apart from a reduction in the wild bee population through the cutting down of forests, other factors led to a decline in mead production. The Reformation reduced the large demand for church candles, which had been made from beeswax. The importation of sugar in large quantities also dealt a heavy blow to the beekeeping industry. When modern beekeeping developed, its dependence on the honey extractor meant that combs were no longer cut up to extract the honey, so no residue was left for mead making. In any case the prestige of mead was low and no revival of mead making occurred in England until the years following the second World War. Then G. R. Gayre, from whose book[1] on mead these historical details are taken, started a factory in Cornwall.

Many tons of bush honeys, mainly from Manuka (*Leptospermum scoparium*), kamahi (*Weinmannia racemosa*), and rewarewa (*Knightia excelsa*) are produced in New Zealand each year. In addition, much honey from buttercups (*Ranunculus spp.*), is harvested.

If such honeys are unblended, they are usually difficult to sell in large amounts on the local and overseas markets because they have a strong flavour, a dark colour, or both these characteristics. If these honeys could be more readily marketed, there is no doubt that, with the exception of honey from buttercups, their production could be greatly expanded.

It was considered that such honeys might be used for the production of honey mead. Although mead is often made on a small scale by New Zealand beekeepers, no experimental production under controlled conditions had been undertaken. Furthermore, it was not known if it were possible to produce satisfactory meads from the more strong-tasting honeys. Accordingly, the following experiments were carried out to provide a basis of knowledge on which an industry might be developed. Honeys of pure floral source are seldom obtainable in practice, and the names under which honeys are referred to in this paper indicate the predominant honey in their composition.

Experimental Procedure

Although many recipes are available for producing mead in small quantities for home consumption, it was considered that a different approach would be necessary for commercial production. Fermentation usually occurs in two stages, primary and secondary, which merge into each other, particularly when sweet meads with a high initial sugar content are being prepared. During the primary fermentation, which may last for up to three weeks, nearly all the alcohol is produced and much CO_2 is evolved. The secondary stage is one during which the mead matures, and slow fermentation of the remaining honey occurs, through the yeast gradually adapting itself to the high concentration of alcohol. This period may last for up to two years[2].

It was thought that for commercial production it would simplify manufacture if, when primary fermentation ceased, the mead could be clarified, filtered free of yeasts, and matured for the necessary period without further fermentation. When desired, the mead could be fortified before ageing commenced.

In the U.S.A., Filipello and Marsh[3] have described a method of fermenting local honeys to produce mead which aged rapidly when filtered after the primary fermentation. They showed that the addition of certain salts to the honey solution assisted fermentation and increased the yield of alcohol. The following combination of salts gave the best results:

Cream of Tartar	0.2%	by weight of solution
Ammonium phosphate (Tribasic)	0.1%	" " " "
Citric acid	0.5%	" " " "
Magnesium chloride	0.025%	" " " "
Calcium chloride	0.025%	" " " "

Experiments were undertaken using the above and other combinations of salts so that the most satisfactory one necessary for the production of high quality meads could be found. When the above combination of salts is used it is referred to as "F. and M." in this paper.

Manuka Meads

Low grade manuka honey was dissolved in tap water, kept at a temperature of 160°F. for 1 hr. to pasteurise the solution, and then made up to a volume of either 2½ or 8 l., containing 30% by weight of honey sugars and the appropriate salts. The solution was inoculated with a pure culture of yeast and fermented in an incubator at 78°F. in flasks or glass vessels fitted with bubblers to allow the CO_2 generated to escape.

When the primary fermentation was completed the evolution of CO_2 had virtually ceased, and it was at this stage that the mead was clarified, suspended matter and particles of wax being removed by filtration. Lothrop and Paine[4] have shown that much of the cloudiness in honey is due to positively charged colloids which can be flocculated by the addition of bentonite, the particles of which have a negative charge. Filipello and Marsh[3] applied this method to clarifying mead, finding that a suspension of bentonite in water at a concentration of 5 g. per 100 ml. was satisfactory. After the addition of the bentonite suspension, at the rate of 5 ml. per 100 ml. mead, the mead was easily made clear by filtration. At Wallaceville it was found that a bentonite suspension in the above strength clarified the mead satisfactorily, but filtration was very difficult owing to the clogging of the filter paper in the Buchner. This was overcome by the addition of 1 per cent $\frac{W}{V}$ filter aid (Dicalite) to the mead, and the formation of a thin layer of filter aid on the filter paper before filtration. After filtration the mead was passed through a 14 cm. clarifying filter pad (Hormann EKWIP. D.6) to "polish" it and remove yeast cells which might cause secondary fermentation. A vacuum of approximately 5 in. was used in filtration, and the bentonite was suspended not in water but in a portion of the mead being filtered. The bentonite was added at the rate of 0.25 g. per 100 ml. mead. The method gave excellent results and the filtered solutions of mead retained their brightness under varying conditions of temperature.

Unless otherwise stated, the methods described for fermenting manuka honey and clarifying the mead produced were used throughout this work. Except in the case of sweet meads the solutions of honey were always fermented at a strength of 30 per cent by weight of honey sugars, an allowance being made for the water content of the honey.

Table I shows results obtained from fermentation of manuka honey solutions containing various combinations of salts.

Discussion of Table I: All the manuka meads dealt with in this table are dry meads, *i.e.* meads in which most of the sugars initially present are broken down during the fermentation. Fermentation was continued until the evolution of CO_2 had virtually ceased.

When the Filipello and Marsh formula for added salts (Nos. 3, 4, 6) was used, alcohol content varied from 11.5 to 12.9 per cent, and the final pH averaged 3.3. After filtration the meads retained bright-

TABLE I. MANUKA MEADS

Type Fermentation	No.	Time fermented (days)	% Alcohol by volume	pH at start	pH at end	S.G. at start	S.G. at end	Date of filtration	Volume fermented (l.)	Consumer grading June, 1953		Remarks
										Average for six consumers	Viticulturist	
F. and M.	3	22	12.9	—	3.2	—	1020	18/3/52	2.5	2	3	See Table V.
F. and M.	4	24	12.5	—	3.3	—	1028	21/3/52	2.5	1	1	
F. and M.	6	23	11.5	—	3.3	—	1044	31/3/52	8	1	1	See Table V.
No salts added	9	24	5.6	4.1	3.9	1108	1076	Distilled to provide alcohol	8	Not submitted. Sweet, poor taste; bacterial growth occurred	—	
F. and M. except potassium bitartrate omitted	16	30	12.9	3.1	3.0	1106	1028	21/8/52	8	2	1	
F. and M. except potassium bitartrate halved	17	17	14.4	3.4	3.1	1110	1026	14/8/52	70	3	3	See also Table I.
F. and M. except citric acid omitted	21	29	12	4.5	3.6	1110	1037	11/9/52	8	2	2	
F. and M. except citric acid halved	23	28	11.1	4.0	3.5	1112	1050	29/9/52	8	2	2	
F. and M. except ammonium phosphate omitted	22	63	7.9	2.9	3.0	1110	1069	23/10/52	8	Not submitted; Taste poor	—	
F. and M. except calcium chloride and magnesium chloride omitted	20	33	10.36	3.3	3.3	1114	1054	10/9/52	8	1	2	
F. and M. except citric acid and potassium bitartrate omitted	12	34	11.4	6.4	4.1	—	1038	28/5/52	8	Not submitted; Taste poor	—	

ness, but deposition of tartrate crystals occurred. These were easily removed by siphoning off the top layer of mead, or by filtration. No further fermentation took place and bacterial contamination was absent, due to the low pH and fairly high alcoholic content. A low pH, which favours rapid yeast growth, renders the sugar solution unlikely to support the growth of bacteria.

Fermentation without the addition of salts was unsatisfactory (No. 9), a product with a low alcoholic content and high pH being obtained. These factors caused bacterial growth soon after filtration.

Omission of ammonium phosphate (No. 22) caused production of a mead with low alcoholic content. When citric acid and potassium bitartrate were omitted (No. 12), an unsatisfactory mead resulted.

Omission of citric acid (No. 21) and halving the usual weight of citric acid (No. 23) did not adversely affect the meads produced, except that the final pH was somewhat higher than usual, which would render them more liable to spoilage.

Halving the usual weight of potassium bitartrate or omitting it, produced meads with a low pH (Nos. 16 and 17).

The figures quoted under the heading "consumer grading" in the table, were arrived at as follows. Six average males were asked to place the meads in one of the three groups denoted by numbers, Grade 1 being a mead they enjoyed most, Grade 3 being a mead enjoyed least, and Grade 2 being in an intermediate class. Six samples at a time were tested, and the results averaged. This method is used throughout the paper.

Mr. F. Berry-Smith, Viticulturist, Department of Agriculture, Auckland, provided the figures given under the heading "Viticulturist".

It appears the the best meads are generally produced by not varying the original Filipello and Marsh formula.

Throughout this paper, alcohol is always given as the percentage present by volume.

Various Meads

Table II shows results obtained by fermenting various honeys. The meads produced all had characteristic flavours. Pohutukawa was graded highest, followed by kamahi and clover meads.

For the pohutukawa meads fermentation was slower than usual.

The clover mead was produced from the highest grade of honey. As such honey finds a ready market, it would not normally be used in mead production. Clover meads were comparable with other meads in alcohol content and final pH, were milder to the palate than manuka meads and could be drunk soon after preparation.

TABLE II. VARIOUS MEADS

Type Fermentation	No.	Time fermented (days)	% Alcohol by volume	pH at start	pH at end	S.G. at start	S.G. at end	Date of filtration	Volume fermented (l.)	Consumer grading June, 1953	
										Average for six consumers	Viticulturist
F. and M. REWAREWA HONEY	7	23	13.5	—	3.3	—	1018	1/4/52	8	3	2
F. and M. BUTTERCUP HONEY	1	21	12.9	—	3.4	—	1020	14/3/52	2.5	3	3
F. and M. BUTTERCUP HONEY	2	22	13.8	—	3.5	—	1008	17/3/52	2.5	3	3
F. and M. KAMAHI HONEY	19	22	12.9	3.5	3.5	1116	1047	29/8/52	8	2	2
F. and M. KAMAHI HONEY	28	41	14.6	3.4	3.5	1118	1036	28/1/53	12	2	1
F. and M. but potassium bitartrate halved POHUTUKAWA HONEY	18	55	9.5	3.5	3.0	1109	1054	27/8/52	8	1	1
F. and M. POHUTUKAWA HONEY	26	52	15.5	3.3	3.4	1116	1028	1/12/52	8	3	3
F. and M. CLOVER HONEY	5	25	12.8	—	3.2	—	1040	31/3/53	8	Not tested owing to fermentation	1
F. and M. CLOVER HONEY	11	22	11.5	3.3	3.2	1164	1038	22/4/52	20	2	2

TABLE III. SWEET MEADS

Type fermentation	No.	Time fermented (days)	% Alcohol by volume	pH at start	pH at end	S.G. at start	S.G. at end	Date of filtration	Volume fermented (l.)	Consumer grading June, 1953	
										Average for six consumers	Viticulturist
F. and M. MANUKA HONEY	15	37	12	3.3	3.5	1136	1080	7/8/52	8	2	2
F. and M. but Citric acid wt. doubled. MANUKA HONEY	14	59	11	—	3.1	1132	1086	4/8/52	8	1	2
F. and M. POHUTUKAWA HONEY	29	53	9.1	3.1	3.2	1145	1074	16/2/53	20	1	1
F. and M. KAMAHI HONEY	30	63	11.2	3.4	3.5	1145	1070	27/2/53	8	2	2
F. and M. REWAREWA HONEY	31	55	13	3.0	3.3	1140	1056	2/3/53	8	2	2
F. and M. CLOVER HONEY	32	58	10.9	3.0	3.4	1145	1072	6/3/53	8	2	2

Sweet Meads

Addition of honey to meads after fermentation did not give a satisfactory product. Accordingly, the strength of sugars in solutions before fermentation was increased so that when fermentation was over there would be sufficient residual sugars to render the mead sweet. One and a quarter times the usual weight of sugars was used.

It will be seen from Table III that fermentation was slower than usual because of the higher sugar content of the solutions. The final specific gravity was high, owing to residual sugar, and the taste of the meads was much sweeter than that of the usual dry meads in which residual sugars are low. Citric acid was doubled for No. 14 as it was thought that the resulting lower pH would counteract excessive sweetness.

It is interesting to note that none of these meads were below Grade 2, and as in the case of the dry meads, manuka and pohutukawa were Grade 1.

Production of Mead in Tanks

Various types of mead were fermented in a stainless steel tank in 70-l. volumes. (See Table IV.) The tank was sterilized by autoclaving, but otherwise the same procedure was followed as with smaller vessels. The tank was placed in an open drum of water which was maintained at 78°F. by a circuit containing heater, thermostat, and stirrer. During fermentation the tank was covered with a lid which allowed CO_2 to escape but prevented the loss of alcohol by evaporation, which could be as high as 50 per cent. This was found to occur towards the end of fermentation if the lid was not used.

Fermentation proceeded faster in tanks than in smaller vessels. No difficulties were encountered, and fermentation in much larger tanks for commercial production of meads should be straightforward.

Effect of Activated Charcoal on Meads

Meads and fortified meads were treated with activated charcoal (Norit A) added at the rate of 2 g. per 500 ml. It was found that shaking the mead containing the charcoal for three hours was as effective as standing for up to six weeks with occasional shaking. After treatment the charcoal was filtered off with a filter pad.

It will be seen from Table V that manuka mead, both fortified and unfortified, was greatly improved in flavour by the use of charcoal. Buttercup and pohutukawa meads showed no improvement but rewarewa mead was improved. Clover mead showed improvement only when fortified. In the case of kamahi and rewarewa meads, improvement, if effected, was slight. Brandies from clover, manuka, rewarewa, and pohutukawa meads were improved by the charcoal treatment.

It is not surprising that fortified meads, honey brandies, and honey liqueurs are improved by treatment with charcoal, as

TABLE IV. CHARACTERISTICS OF MEADS FERMENTED IN 70 LITRE VOLUMES

Type fermentation	No.	Time fermented (days)	% Alcohol by volume	pH at start	pH at end	S.G. at start	S.G. at end	Date when Filtration carried out	Consumer grading June, 1953		Remarks
									Average for six consumers	Viticulturist	
F. and M. MANUKA HONEY	13	16	12.9	3.3	3.3	1104	1022	27/6/52	3	3	8 l. starter added
F. and M. but half usual wt. potassium bitartrate MANUKA HONEY	17	17	14.4	3.4	3.1	1110	1026	14/8/52	3	3	3 l. starter added
F. and M. CLOVER HONEY	11X	19	11.4	3.1	3.0	—	1034	20/5/52	2	2	1 l. starter added
F. and M. POHUTUKAWA HONEY	27	14	16.4	3.3	3.3	1114	1020	12/11/52	2	1	3 l. starter added

TABLE V. EFFECT OF ACTIVATED CHARCOAL ON MEADS AND FORTIFIED MEADS

Type of Mead	No.	Result of Treatment
Clover	11X	No improvement
Clover	5	No improvement
Clover fortified to 20% alcohol	11X	Marked improvement
Clover fortified to 30% alcohol	11X	Marked improvement
Buttercup	2	No improvement
Rewarewa	7	Slight improvement
Rewarewa	24	Slight improvement
Rewarewa	31	Untreated sample preferred
Kamahi	19	Slight improvement
Kamahi	28	No improvement
Kamahi	30	Untreated sample preferred
Pohutukawa	26	No improvement
Pohutukawa	27	No improvement
Manuka Sweet	15	Improvement
Manuka	13	Marked improvement
Manuka fortified to 20% alcohol	13	Marked improvement
Manuka fortified to 30% alcohol	13	Marked improvement
Manuka fortified to 42% alcohol	13	Marked improvement

adsorption would occur of undesirable products produced during fermentation and distilled off with the alcohol used in their fortification. Brandies are often aged in oak casks the insides of which are charred to produce charcoal, on which adsorption occurs. Manuka honey frequently has a strong, bitter flavour, and it is probable that adsorption by the charcoal of the substances causing this, rather than adsorption of undesirable products of fermentation, accounts for the improvement in flavour of unfortified manuka meads. It is significant that the flavours of unfortified buttercup and clover meads are not improved by treatment with charcoal, but fortified clover mead is improved.

It was considered that it would be an advantage when producing meads to carry out the fermentation in the presence of activated charcoal, thus avoiding the shaking or stirring necessary if meads are treated with charcoal after fermentation. Accordingly, fermentations were carried out in this way, charcoal (Norit A) being added at the rate of 2 g. per 500 ml. of liquid. It was found that the charcoal remained in suspension throughout fermentation, being buoyed up by the CO_2 evolved. Results in Table VI show that such fermentations are straightforward. However, insufficient were carried out for the effect of the charcoal on consumer grading to be studied.

Ageing of Meads

All the meads produced were left to age in glass. Manuka mead No. 13 was fortified to 20 per cent alcohol and left to age

TABLE VI. CHARACTERISTICS OF MEADS FERMENTED IN THE PRESENCE OF ACTIVATED CHARCOAL.

Type fermentation	No.	Time fermented (days)	% Alcohol by volume	pH at start	pH at end	S.G. at start	S.G. at end	Date of filtration	Volume fermented (l.)	Consumer grading June, 1953	
										Average for six consumers	Viticulturist
F. and M. REWAREWA HONEY	24	17	15.3	3.4	3.3	1110	1004	29/9/52	70	2	2
F. and M. MANUKA HONEY	25	49	13	3.5	3.3	1114	1039	29/10/52	8	Fermentation occurred	—

in a 5-gal. oak cask and a glass vessel. Rewarèwa mead No. 24 and Pohutukawa mead No. 27 were treated similarly.

Honey Brandies and Honey Liqueurs

It has been shown that treatment of manuka meads, fortified meads and brandies with activated charcoal improves their flavour. The addition of high grade clover honey to manuka brandy of 30 per cent strength improves the flavour considerably. Experiments showed that for best results the sweetened brandy should contain a weight of honey equal to one third of its volume. Thus 540 ml. of brandy would contain 180 g. of honey. The sweetened brandy is prepared by diluting brandy of a high alcoholic content with the appropriate volume of distilled water containing the honey. Filtration is necessary.

It was found that a pleasant honey liqueur of 42 per cent manuka alcohol could be prepared by the addition of the same proportion of clover honey as was used in the 30 per cent brandy.

A honey liqueur of 54 per cent manuka alcohol was prepared, it being found necessary to mask the alcohol by the addition of a weight of honey equal to one half of the volume of the liqueur. The honey was added direct to manuka alcohol of 81 per cent in which it did not dissolve, shaking being necessary to bring about an even suspension. Filtration could not be attempted. The liqueur had a pleasant flavour.

Clover mead was fortified to 20 per cent, using clover alcohol, and the fortified mead treated with activated charcoal. Clover brandy of 30 per cent strength and clover liqueurs of 42 and 54 per cent were prepared as in the case of manuka.

All these clover and manuka preparations were left to age in glass.

Carbonation of Meads

Meads prepared by the methods described are known as still meads. It is possible, however, that a market might exist for small bottles of sparkling mead. Various meads were carbonated in a soda water syphon and consumer tests applied. There is no doubt that these carbonated meads appealed more to some palates than did the still meads.

Discussion

The fermentations carried out in 16-gal. tanks show that commercial production of meads should not be difficult. The small quantities of chemicals added to the honey solutions to assist fermentation are inexpensive and readily obtainable. Pure cultures of yeast must be maintained and used for inoculating the solutions. Their maintenance would be a routine procedure for a bacteriological laboratory which would supply them as required. The meads described in this article were prepared with two yeasts which appeared to give similar results. One has been maintained for years at Wallaceville as a stock culture and the other, a

Burgundy wine yeast, was obtained through the courtesy of Mr. D. G. Quinn, Viticulturist, Department of Agriculture, Victoria.

The bentonite used for clarifying the mead is a New Zealand product and its cost is negligible. Although filter aid is imported, and its cost is higher than that of bentonite, it is used in such small quantities that expenditure on it per gallon of mead would be very small. Filtration of the meads in the laboratory was carried out by negative pressure but on a commercial scale it would be more satisfactory to pump the meads under pressure through filter pads.

In the preparation of dry meads approximately 16 gal. of mead are produced from 58 lb. of honey, i.e., 1 gal. mead from 3.6 lb. of honey. With the price of manuka honey at 7¾d. per lb., the honey used per gallon of mead would cost 2/4. Sweet meads require one and a quarter times the usual weight of honey in their production, i.e., 1 gal. mead from 4.5 lb. honey. The cost of the honey used per gallon of manuka sweet mead would be approximately 2/11.

Assuming a mead contains 12 per cent alcohol, 1 gal. would yield approximately 0.74 pt. (432 ml.) of 100 per cent alcohol, allowing for a distillation loss of 20 per cent. This would produce 2.5 pt. (1,440 ml.) of 30 per cent honey brandy or 1.8 pt. (1,029 ml.) of 42 per cent honey liqueur. It would be necessary to add clover honey to these to improve the flavour. (See Table VII.)

One ton of manuka honey, costing £72 6s. 8d. (7¾d. lb.), yields approximately 60 gal. absolute alcohol, allowing for a distillation loss of 20 per cent.

Blending could be used to improve the flavour of the stronger meads.

Fortification of meads should protect them from subsequent attacks by yeasts and bacteria. Unfortified meads, on the other hand, are liable to such attack, and at Wallaceville, secondary fermentation, caused by yeasts, occurred in several meads. In Australia it is common practice to prevent secondary fermentation of wines by the addition of SO_2 as recommended by Fornachon[5]. He estimates the amount of SO_2 required to provide protection as 100 parts per million. A similar concentration of SO_2 in mead has been found to prevent secondary fermentation and has no affect on the flavour. The correct concentration of SO_2 can be conveniently obtained by the addition of potassium metabisulphite at the rate of 0.2 g. per litre of mead.

Mead produced from clover honey resembles a light table wine and could be drunk without ageing. Manuka and other meads improve with ageing.

The most promising meads according to consumer tests were picked out and judged by a panel consisting of a Honey Grader, two Apiary Instructors, and an experienced consumer, who placed them in the following order of merit: Manuka sweet mead (No. 14); clover (No. 11); manuka (No. 6); manuka (No. 4); pohutukawa (No. 29, and No. 18) (the last three equal); kamahi (No. 30), and rewarewa (No. 7) (equal) and buttercup (No. 1).

TABLE VII. APPROXIMATE COST OF HONEY USED IN PRODUCING MEADS, HONEY BRANDIES, AND LIQUEURS

Honey	Bulk Honey Price per lb.	Cost of 3.6 lb. various honeys used in producing 1 gal. mead from which can be obtained 2.5 pt. 30% Brandy or 1.8 pt. 42% Liqueur	Cost of Clover Honey used to sweeten 30% Brandy and 42% Liqueur obtained from 1 gal. Mead		Total Cost of 30% Brandy and 42% Liqueur obtained from 1 gal. Mead	
			30% Brandy	42% Liqueur	30% Brandy	42% Liqueur
MANUKA	7.75d.	2/4	1/-	9d.	3/4	3/1
REWAREWA	8.85d.	2/8	1/-	9d.	3/8	3/5
KAMAHI BUTTERCUP PENNYROYAL	9.5d.	2/10	1/-	9d.	3/10	3/7
POHUTUKAWA	10.25d.	3/1	1/-	9d.	4/1	3/10
CLOVER	11.84d.	3/7	1/-	9d.	4/7	4/4

A range of meads produced by a well-known English company was tasted. These consisted of straight mead, Bochet, Tyser, Sack mead, Pyment, Hippocras, Sack Metheglin, and Melomel.

The straight mead was placed well below the best of the New Zealand meads prepared in the course of this work. The other English meads could not be compared with New Zealand meads, as they were compound meads containing spices and grape and other fruit juices. The best of them was considered to be the Pyment.

Brandies produced on a small scale from manuka, clover, rewarewa, and pohutukawa meads showed such promise that a more detailed investigation will be undertaken. Alcohol distilled from meads and treated with activated charcoal made an excellent potent spirit considered ideal for gin production. Approximately 500,000 bottles of gin could be produced from 500 tons of manuka honey.

Mead could easily be carbonated and put up in small bottles. Carbonation of large bottles of mead would not be advisable as the contents would probably not be all consumed at once and would become flat.

An important point in considering the economics of producing meads and spirits from honeys is that in the case of bush honeys they would be produced from what is virtually an unexploited source of supply. Usually alcoholic drinks and spirits are produced from crops such as grains, which are valuable foods and could be more profitably used to help feed an increasingly hungry world.

The main difficulty in establishing a mead industry would lie in building up a demand for what is a completely new drink. It would first be necessary to find what type of mead or mead products appear to have the widest appeal and then advertise these extensively. It is probable that sweet meads, honey brandies, liqueurs, and gins, would be more popular than dry meads.

ACKNOWLEDGMENTS

The author wishes to acknowledge the help of Mr. F. Berry-Smith, Viticulturist, Department of Agriculture, in appraising mead samples and suggesting the use of brandy from mead for gin production. The honey and some of the equipment used in the work was supplied by the Marketing Division, Department of Agriculture, at whose request this investigation was undertaken.

REFERENCES

1. GAYRE, G. R., 1948: "Wassail! in Mazers of Mead." Phillimore, London, p. 176.
2. DENNIS. C. B., 1952: *Bee Craft. 34*: 62.
3. FILIPELLO, F.; MARSH, G. L., 1934: *Amer. Bee J.* Dec. p. 537.
4. HALL, H. H.; LOTHROP, R. E., 1934: *J. Bact., 27*: 349.
5. FORNACHON, J. C. M., 1943: "Bacterial Spoilage of Fortified Wines." Hassell Press, Adelaide. p. 126.

SEED DISINFECTION

IX. CONTROL OF ONION SMUT (*Urocystis Cepulae* Frost)

By I. A. M. CRUICKSHANK* and H. JACKS, Plant Diseases Division, Department of Scientific and Industrial Research, Auckland

(Received for publication, 30 September 1953)

Summary

In glasshouse tests, materials based on thiram gave better control of onion-smut than calomel.

In field trials, seed dressed with thiram compounds (at 50 per cent by weight) reduced smut infection to approximately the same degree as Formalin-drip treatment of soil in drills.

To secure satisfactory control with thiram-based compounds it was necessary to use materials containing not less than 50 per cent active material, applied at 50 per cent of seed weight.

Seed treated with thiram gave significantly higher emergence than either untreated seed or that sown with Formalin-drip treatment.

INTRODUCTION

Onion-smut (*Urocystis cepulae* Frost.) was first recorded in New Zealand by Gibbs (1938) in the peaty soils of the Marshland district of Canterbury. Of various control measures tested, Gibbs *et al.* (1940) found Formalin-drip treatment to be the most effective.

Reports from overseas (Newhall, 1944) suggested that heavy coating of onion seed with fungicides was promising for control of onion-smut. Croxall and Hickmann (1953) reported that seed treatments were ineffective for control of onion-smut in glasshouse tests under conditions of heavy soil infection and optimum temperature for development of the disease. Nelson (1946) and Larson and Walker (1952), however, reported on favourable results obtained with seed treatments under field conditions.

In this paper the results are reported of trials carried out on Marshland soil to investigate the efficacy of seed-dressings as compared with Formalin-drip treatment.

MATERIALS AND METHODS

Seed of the variety Pukekohe Long Keeper was used in all tests.

The following materials were tested:

Thiram, technical tetramethyl thiuram disulphide;

Thirodust, a seed-dust containing 75 per cent micronized thiram;

Fernasan, a seed-dust containing 50 per cent thiram;

Calomel, 85 per cent mercurous chloride;

Formalin, a 40 per cent solution of formaldehyde.

A resin-methylated spirit sticker (Jacks, 1952) was applied at 0.5 per cent of seed weight prior to dust treatment. One per cent Formalin

*Stationed at Crop Research Division, Department of Scientific and Industrial Research, Christchurch.

solution was applied at the rate of 120 gal. per acre as recommended by Gibbs *et al.* (1940).

Conditions under which the various trials were carried out are described below.

Counts of emergence and of smut-infected plants were made when onion seedlings were in the first leaf stage.

RESULTS

Experiment I

The first field trial was sown in October, 1951. Seed was sown with a standard drill at 1-in. depth. Drills were 12 in. apart and 60 ft. long. The rate of sowing was 4 to 5 lb. of seed per acre. Four replications of three drills were used for each treatment. The mean soil temperature in October, 1951, was 10.7° c. Three strips of 6 ft. length were examined in the centre drill of each replicate.

Results are given in Table I.

TABLE I. FIELD TRIAL 1951: CONTROL OF ONION-SMUT BY SEED DRESSINGS AND FORMALIN-DRIP TREATMENT

Treatments (concentrations)	Smut infection	
	Mean percentage	Transformed
Check (sticker only)	80.5	63.8
Thirodust (50% of seed weight)	28.5	32.3
Calomel (50% of seed weight)	44.7	42.0
Formalin (1% at 120 gal. per acre)	20.9	27.2
Difference for significance at: 5%	—	5.8
1%	—	8.1

All treatments significantly reduced smut infection as compared with check. Formalin and Thirodust were comparable in effectiveness and gave significantly better control than calomel.

Experiment II

Two glasshouse tests were carried out to study the effect of thiram formulations on emergence and on smut control. Marshland soil (pH 4.95) was inoculated with onion smut spores at the rate of 2g. per box (18 in. × 12 in. × 3 in.). Five boxes were used for each treatment. Spores were diluted with bentonite at ten times their weight to ensure equal distribution and worked into the top inch of soil. Fifty seeds were then sown per box. Glasshouse temperatures ranged from 18 to 21° c. All plants were examined for smut infection. A com-

bined analysis was carried out of the two tests since preliminary analysis showed no significant differences between trials. Results are given in Table II.

TABLE II. GLASSHOUSE TRIALS: EFFECT OF THIRAM FORMULATIONS ON CONTROL OF ONION-SMUT

Treatments	Concentrations in percentages of seed weight	Mean percentage emergence	Smut infection	
			Mean percentage	Transformed
Check	Sticker only	54.7	96.9	79.8
Fernasan	50.0	82.8	60.2	50.9
Fernasan	25.0	80.0	75.2	60.1
Fernasan	12.5	83.2	85.5	67.6
Thirodust	50.0	85.4	68.4	55.8
Thirodust	25.0	90.0	78.2	62.2
Thirodust	12.5	90.1	80.2	63.6
Thiram	50.0	76.0	76.8	61.2
Thiram	25.0	72.8	68.6	55.9
Thiram	12.5	73.5	79.0	62.7
Thiram	6.25	81.8	75.9	60.6
Difference for significance at: 5%		9.2	—	7.0
1%		12.2	—	9.3

All treatments significantly increased emergence over check. Thirodust and, to a lesser extent, Fernasan brought about higher emergence in comparison with thiram. Smut infection was significantly reduced by all treatments. The higher concentrations of seed dressings brought about greater reduction of infection.

Experiment III

In a field trial sown in September, 1952, treatments were replicated four times, each replicate consisting of six drills 14 in. apart and 8 ft. long. Each of the drills was sown with 150 seeds. The mean soil temperature for September, 1952, was 8.4° c. All seedlings in three inside drills of each replicate were examined for smut infection. Results are given in Table III.

Seed dressings with Thirodust and Fernasan gave significant increase of emergence as compared with Formalin and check. Emergence in Formalin plots was significantly higher than in check. All treatments gave significant reduction of smut infection.

Two further trials were carried out on a grower's property, each covering half an acre. In each of these, seed dressed with Thirodust and Fernasan at 50 per cent of seed weight was compared with untreated seed. The degree of control was similar to that recorded in Table III. Differences between the two thiram formulations were not significant.

TABLE III. FIELD TRIAL 1952: EFFECT OF SEED DRESSINGS AND FORMALIN-DRIP TREATMENT ON CONTROL OF ONION-SMUT

Treatments (concentrations)	Mean percentage emergence	Smut infection	
		Mean percentage	Transformed
Check (sticker only)	62.1	66.1	54.4
Thirodust (50% of seed weight)	92.7	5.4	13.5
Fernasan (50% of seed weight)	88.1	4.7	12.6
Formalin (1% solution at 120 gal. per acre)	72.3	8.2	16.6
Difference for significance at: 5%	5.7	—	6.1
1%	8.1	—	9.2

DISCUSSION

Heavy coating of seed with fungicidal dusts is necessary for control of onion-smut; as this affects normal flow of seed through drills, particular attention should be given to seeding rate and to adjustment of drill openings to ensure the correct rate of discharge.

Results of glasshouse tests confirmed the findings of Croxall and Hickmann (1953) that satisfactory control cannot be obtained with heavily infected soil and under optimum temperature conditions for smut infection. Results of field experiments showed that satisfactory control can be obtained with thiram seed dressings when the level of smut infection was lower than that used in the glasshouse tests and where soil temperatures were below optimum for disease development. Under these conditions thiram seed dressings were of comparable effectiveness to the Formalin-drip treatment. Similar results were obtained by Nelson (1946), and Larson and Walker (1952).

CONCLUSION

Seed dusts containing not less than 50 per cent of thiram when applied at 50 per cent of seed weight, were as effective in control of onion-smut as Formalin-drip treatment.

ACKNOWLEDGEMENT

Thanks are expressed to Miss E. Milne, of the Applied Mathematics Laboratory, Department of Scientific and Industrial Research, for statistical analysis of results, and to Mr. H. B. Hibbard, Marshland Rd., Christchurch, on whose property field trials were carried out.

REFERENCES

CROXALL, H. E.; HICKMANN, C. J., 1953: *Ann. Appl. Biol. 40*: 176-83.
GIBBS, J. G., 1938: *N.Z. J. Sci. Tech. A20*: 65-8.
GIBBS, J. G.; BAYLIS, G. T. S.; BLACKMORE, L., 1940: *Ibid. A22*: 162-6.
JACKS, H., 1952: *Ibid. A34*: 202-5.
LARSON, R. H.; WALKER, J. C., 1952: *Phytopath. 42*: 469.
NELSON, R., 1946: *Quart. Bul. Mich. Agric. Exp. Sta. 28*: 226-47.
NEWHALL, A. G., 1944: *Plant Dis. Rep. Suppl. 145*: 39-45.

NOTE ON THE SETTING UP OF A BATTERY OF SMALL LYSIMETERS

By C. A. SMITH, Grasslands Division, Department of Scientific and Industrial Research, Palmerston North.

(Received for publication, 14 September 1953)

A simple method of removing intact soil cores and installing them to form a battery of small lysimeters has been developed.

The method consisted in digging round and isolating a column of soil a little larger than 18 in. diameter. A thin, 22 gauge steel cylinder, 18 in. diameter and 2 ft. in length, was placed on top of the soil column and forced down by the repeated dropping of a weight on a wooden platform resting on top of the cylinder. It was found necessary to strap a detachable, circular, ¼-in. steel band round the lower edge of the steel cylinder to prevent distortion. As the cylinder was driven downwards it pared away the surplus soil, leaving an intact core fitting tightly against the inside of the cylinder. When the cylinder was completely filled, the soil core was undercut, and cylinder plus encased core lifted on a derrick and removed to the experimental site.

After 8–10 weeks to allow the soil core to dry, the thin, steel cylinder was cut open, exposing the soil core, which was painted (except top and bottom) with several coats of a polyvinyl chloride-acetate solution.

This sealed all worm channels, small cracks, etc. The solvent used was two parts of acetone to one of methyl isobutyl ketone. A layer of asphaltic-asbestos compound was placed round the soil core a little below the upper edge. The steel cylinder was then restrapped round the soil core, tightly squeezing the asphaltic seal, and thus minimising the danger of drainage outside the plastic sheath. This appears to seal the core effectively and to ensure percolation only through the mass of soil.

The cylinders were finally mounted on funnels set in a concrete platform, the drainage passing to collecting bottles below. The cylinders rested on ¼-in. perforated steel plate, which fitted inside the funnels. The join between cylinder and funnel was sealed with asphaltic-asbestos compound to form one complete unit. Soil was packed round the lysimeters to simulate natural soil temperatures.

The advantage of a battery of small lysimeters is that their low cost and ease of installation allow the use of larger numbers, resulting in adequate replication.

FIG. 1.—Final stage in the digging and isolation of an intact soil core. The downward-driven steel cylinder has pared away surplus soil from the isolated soil column. *Photo: J. P. Lambert.*

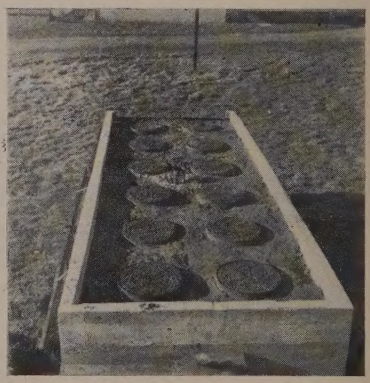


FIG. 2.—The lysimeters installed in a raised concrete trough; rain gauge in centre. *Photo: J. P. Lambert.*

BULLETINS OF THE DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH

No.
1-4. (Out of print.)
5. PLANT-BREEDING METHODS AND RESULTS. F. W. Hilgendorf. Price, 6d.
6. REPORT ON THE FISCHER PROCESS. H. O. Askew. Price, 6d.
7. NEW ZEALAND WOOL FIBRES. (Out of print.) E. F. Northcroft. Price, 6d.
8. SUMMARY OF INVESTIGATIONS ON NEW ZEALAND COAL. W. Donovan. Price, 6d.
9-10. (Out of print.)
11. BUILDING STONES OF NEW ZEALAND. P. Marshall. Price, 4s.
12. REPORT OF THE NUTRITIVE VALUE OF MEAT MEALS. (Out of print.) E. A. Pope.
13. YIELD OF CHEESE PER POUND OF BUTTERFAT. P. O. Veale. Price, 9d.
14. LOW TEMPERATURE CARBONIZATION OF NEW ZEALAND COALS. 1. WAIKATO COAL. W. A. Joiner. Price, 9d.
15. PEACH CULTURE. (Out of print.) K. M. Curtis and T. Rigg. Price, 1s.
16. COLD STORAGE OF FRUIT INVESTIGATIONS OF 1927 AND 1928. L. W. Tiller. Price, 6d.
17. PIG RECORDING, BACON-MANUFACTURE, AND THE PIG INDUSTRY IN NEW ZEALAND. M. J. Scott, C. R. Barnicoat, and F. R. Callaghan. Price, 1s. 6d.
18. GOITRE IN SCHOOL-CHILDREN (Out of print.) R. A. Shore and R. L. Andrew.
19. MOUTERE HILLS PASTURES. T. Rigg and H. O. Askew. Price, 9d.
20. LOW TEMPERATURE CARBONIZATION OF NEW ZEALAND COALS. 2. KAITANGATA AND LINTON COALS. W. A. Joiner. Price, 6d.
21-2. (Out of print.)
23. RELATION OF STORAGE TEMPERATURE TO THE OVERSEAS CARRIAGE OF SOME VARIETIES OF NEW ZEALAND EXPORT APPLES. L. W. Tiler. Price, 6d.
24. A CLASSIFICATION OF THE WAIKATO TYPE OF COAL. W. H. Penseler. Price 1s. 9d.
25. BRONZE BEETLE RESEARCH. A. M. Lysaght. Price, 1s. 6d.
26. INFLUENCE OF SEASON AND FERTILIZER ON THE YIELD AND COMPOSITION OF TYPICAL DAIRYING PASTURES. T. Rigg. Price, 2s.
27. TREATMENT AND DISPOSAL OF DAIRY WASTE WATERS. (Out of print.)
28. WHEAT RESEARCH INSTITUTE: FIRST ANNUAL REPORT, 1929-30.
29. LOW TEMPERATURE CARBONIZATION OF NEW ZEALAND COALS. 3. MILLERTON AND BLACKBALL COALS. W. A. Joiner. Price, 1s.
30. WOOL RESEARCH.
31. INVESTIGATIONS INTO PASTURE PRODUCTION. A. W. Hudson. Parts I, II, III issued. Price, 5s.
32. BUSH SICKNESS. H. O. Askew, T. Rigg, L. I. Grange, N. H, Taylor, and others. Price, 2s. 9d.
33. BUTTERFAT LOSSES IN BUTTERMILK. W. H. Udy. Price, 1s.
34. NUTRITIVE VALUE AND VITAMIN EFFICIENCY OF NEW ZEALAND DAIRY PRODUCE.
35. WHEAT RESEARCH INSTITUTE: SECOND ANNUAL REPORT, 1930-31. F. W. Hilgendorf. Price, 1s. 6d.
36-8. (Out of print.)
39. BRIQUETTING OF NEW ZEALAND COALS. W. A. Joiner, W. G. Hughson, and A. K. R. McDowell. Price, 9d.
40. GOLD-BEARING CONGLOMERATES OF CENTRAL OTAGO. E. O. Macpherson. Price, 9d.
41-3. (Out of print.)
44. THE COMMERCIAL RIPENING OF BANANAS IN NEW ZEALAND. J. B. Hyatt and C. W. O. Turner. Price, 1s.
45. GOITRE IN SCHOOL-CHILDREN. R. A. Shore and R. L. Andrew. Price, 1s. 6d.
46. "CROSS 7" WHEAT. O. H. Frankel. Price, 1s.
47. THE GRASSLANDS OF THE SOUTH ISLAND OF NEW ZEALAND. (Out of print.)
48. WATER-SUPPLIES OF FARMS AND DAIRY FACTORIES IN HAMILTON BASIN AND HAURAKI LOWLAND. N. H. Taylor. Price, 1s. 6d,
49. INTRODUCTION TO THE GRASSES OF NEW ZEALAND. (Out of print.) H. H. Allan.
50. THE CHEESE YIELDING CAPACITY OF MILK. F. H. McDowall. Price, 3s. 6d. (Obtainable from the Dairy Research Institute, Massey College, Palmerston North.)
51. THE CHILLING OF BEEF FOR EXPORT. C. R. Barnicoat. Price, 1s. 3d.
52. INVESTIGATION OF FEED FLAVOUR IN CREAM AND BUTTER. W. Riddet, E. Bruce Levy, and others. Price, 1s.
53. A PRELIMINARY SURVEY OF THE CITRUS INDUSTRY IN NEW ZEALAND.
54. THE LITTLE BARRIER ISLAND. (Out of print.)
55. THE WEST NELSON EARTHQUAKE OF 1929.
56. WHEAT RESEARCH INSTITUTE: FOURTH ANNUAL REPORT. (Out of print.)
57. REPORT OF INTERDEPARTMENTAL COMMITTEE ON SILICOSIS. Price, 1s. 3d.
58-9. (Out of print.)
60. PETROLEUM IN NEW ZEALAND. J. Henderson. Price, 1s.
61 THE SOILS AND AGRICULTURE OF WESTERN SAMOA. W. M. Hamilton and L. I. Grange. Price, 1s.
62. LAND DETERIORATION IN THE HEAVIER RAINFALL DISTRICTS OF NEW ZEALAND.
63. REPORT ON THE ORGANIZATION OF ANIMAL RESEARCH IN NEW ZEALAND. J. Hammond. Price, 1s.
64. GENETICS AND LIVE-STOCK PRODUCTION. (Out of print.) F. W. Dry.
65. SOIL SURVEY OF DUVAUCHELLE BAY-WAINUI DISTRICT, BANKS PENINSULA. C. S. Harris and A. C. Harris. Price, 1s. 3d.
66. A SURVEY OF TUNG GROVES IN NEW ZEALAND. M. M. Burns and N. H. Taylor. Price, 2s.
67. A LIST OF PLANT DISEASES RECORDED IN NEW ZEALAND. R. M. Brien. Price, 1s.
68. WHEAT RESEARCH INSTITUTE: FIFTH ANNUAL REPORT. Price, 1s.
69. SCIENTIFIC AND INDUSTRIAL RESEARCH, 1927-38. Price, 2s. 6d.
70. LAND UTILIZATION REPORT OF THE HERETAUNGA PLAINS. (Out of print.)
71. SOIL SURVEY OF WESTPORT DISTRICT. C. S. Harris and A. C. Harris. Price, 1s. 6d.

BULLETINS OF THE DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH—Continued

No.

72. SOIL SURVEY OF WAIRAU PLAINS, MARLBOROUGH. C. S. Harris and K. S. Birrell. Price, 2s.
73. SURVEY OF THE TUSSOCK-GRASSLANDS OF THE SOUTH ISLAND, NEW ZEALAND. V. D. Zotov. Price, 1s.
74. SOME GROUND-WAVE FIELD-INTENSITY MEASUREMENTS TAKEN IN NEW ZEALAND. G. Searle. Price, 1s.
75. A SURVEY OF THE STANDARDS OF LIFE OF NEW ZEALAND DAIRY-FARMERS. W. T. Doig. Price, 2s. 6d.
76-9. (Out of print.)
80. THE CURING AND COLOURING OF NEW ZEALAND LEMONS. J. B. Hyatt and O. H. Keys.
81. WHEAT RESEARCH INSTITUTE: SIXTH ANNUAL REPORT. (Out of print.) Price, 1s.
82. BOTANICAL ASPECTS OF RAGWORT (SENECIO JACOBAEA L.) CONTROL. A. L. Poole and D. Cairns. Price, 2s. 6d.
83. A HANDBOOK OF THE NATURALIZED FLORA OF NEW ZEALAND. (Out of print.) H. H. Allan. Price, 10s. and 10s. 6d.
84. WHEAT RESEARCH INSTITUTE: SEVENTH ANNUAL REPORT. Price, 1s.
85. THE ECONOMIC IMPORTANCE OF SEAWEEDS (Out of print.) L. B. Moore.
86. MOLE DRAINAGE IN NEW ZEALAND.
87. WHEAT RESEARCH INSTITUTE: EIGHTH ANNUAL REPORT. (Out of print.)
88. FIRECLAY AND GANISTER IN NEW ZEALAND. J. Henderson. Price, 2s. 6d.
89. THE DAIRY INDUSTRY IN NEW ZEALAND. W. M. Hamilton. Price, 2s. 6d. (Out of print.)
90. MILBURN-CLARENDON PHOSPHATE DEPOSITS. E. O. Macpherson. Price, 2s. 6d.
91. NASSELLA TUSSOCK. A. J. Healy. Price, 2s. 9d.
92. SOIL EROSION IN THE HIGH COUNTRY OF THE SOUTH ISLAND. H. S. Gibbs, J. D. Raeside, J. K. Dixon, and A. J. Metson. Price, 5s.
93. INVESTIGATION OF THE CLARENDON PHOSPHATE DEPOSITS. R. W. Willett. Price, 5s.
94. SOILS AND SOME RELATED ASPECTS OF AGRICULTURE IN MID HAWKE'S BAY. I. J. Pohlen and others. Price, 5s.
95. SOIL EROSION IN NEW ZEALAND—PART 1: SOUTHERN HALF OF NORTH ISLAND. L. I. Grange and H. S. Gibbs. Price, 2s. 6d.
96. RHYTHMS IN NEMATODE PARASITISM OF SHEEP. J. H. Tetley. Price, 8s. 6d.
97. REPORT ON BUILDING AND CIVIL ENGINEERING RESEARCH IN NEW ZEALAND. R. E. Stradling. Price, 2s. 6d.
98. INTRODUCED MAMMALS OF NEW ZEALAND. K. A. Wodzicki. Price, 12s. 6d.
99. POISONOUS PLANTS IN NEW ZEALAND. H. E. Connor. Price, 3s. 3d. (4s. quarter cloth).
100. CATALOGUE OF THE DIPTERA OF THE NEW ZEALAND SUB-REGION. D. Miller. Price, 13s. 6d.
101. A REVISED LIST OF PLANT DISEASES RECORDED IN NEW ZEALAND. R. M. Brien and Joan M. Dingley. Price, 5s.
102. A REVISION OF THE MELOLONTHINAE OF NEW ZEALAND. B. B. Given and J. M. Hoy. Price, 12s.
103. NEW ZEALAND-AMERICAN FIORDLAND EXPEDITION. Compiled by A. L. Poole. Price, 7s. 6d.
104. A STATISTICAL STUDY OF LINEN FLAX CROP RECORDS. G. M. Wright. Price, 2s. 6d.

ALL PRICES POST FREE

Order through your Bookseller or from

THE PUBLICATIONS OFFICER, DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH, P.O. BOX 8018, WELLINGTON

and from

THE HIGH COMMISSIONER FOR N.Z., 415 STRAND, LONDON, W.C.2

All Orders should be accompanied by remittance.

To country cheques add exchange (6d.)

Coulls Somerville Wilkie Ltd. 1,250-12-53